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FEASIBILITY STUDIES OF TEN LaGRANGE COUNTY LAKES

FINAL REPORT
Volume 1

FEBRUARY 1992

Presented to:

The Indiana Lake Enhancement Program
Indianapolis, Indiana 46204

Prepared for:

The South Central LaGrange County Water Quality Commission

Division of Soil Conservation
Room W-265

Prepared by:

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FXB Project No. 1206-01

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Executive Summary

This report presents the water quality and modeling results for Indiana Lake Enhancement Program T by 2000 studies of ten Indiana chain lakes in LaGrange County, Indiana. Management alternatives for lake restoration are discussed and general recommendations have been made.

In the ten LaGrange County lakes watershed, land use is approximately 75.8 percent agriculture, 7.1 percent forest, 14.5 percent wetlands and lakes, and 2.6 percent urban/residential. As stated below, most of the sediment and nutrients loadings to all of the lakes originate from agricultural land uses.

Conclusions

Adams Lake

1. The lake has a surface area of 308 acres, a mean depth of 25 feet and a maximum depth of 93 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels fell below 1 mg/L at depth greater than 16 feet. This low dissolved oxygen, coupled with an observed moderate concentration of total phosphorus in the bottom waters of the lake indicate that internal loading of phosphorus from the sediments may be significant.

4. Chlorophyll a concentration in the lake was 2.9 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 1.9 meters.

6. The lake contained moderate concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 33 to 34 eutrophy points and is therefore classified as a Class II (intermediate water quality) waterbody. The lake is classified as mesotrophic by Carlson Trophic State Index.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems account for 8.2 percent of the phosphorus load and 8.5 percent of the nitrogen load to the lake.

Atwood Lake

1. The lake has a surface area of 170 acres, a mean depth of 9 feet and a maximum depth of 33 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels fell below 1 mg/L at depth greater than 16 feet. This low dissolved oxygen, coupled with an observed moderate concentration of total phosphorus in the bottom waters of the lake indicate that internal loading of phosphorus from the sediments may be significant.

4. Chlorophyll a concentration in the lake was 3.0 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 2.1 meters.

6. The lake contained moderate concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 24 to 26 eutrophy points and is therefore classified as a Class I/II (between highest and intermediate water quality) waterbody. According to the Carlson Trophic State Index, the lake is classified as mesotrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems account for 22.1 percent of the phosphorus load and 20.1 percent of the nitrogen load to the lake.

Dallas Lake

1. The lake has a surface area of 283 acres, a mean depth of 35 feet and a maximum depth of 96 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels generally fell below 1 mg/L at depths greater than 20 feet. This low dissolved oxygen, coupled with an observed moderate concentration of total phosphorus in the bottom waters of the lake indicate that internal loading of phosphorus from the sediments may be significant.

4. Chlorophyll a concentration in the lake was 2.6 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 2.1 meters.

6. The lake contained moderate concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 39 to 40 eutrophy points and is therefore classified as a Class II (intermediate water quality) waterbody. According to the Carlson Trophic State Index, the lake is classified as mesotrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems account for 2.5 percent of the phosphorus load and 3.3 percent of the nitrogen load to the lake.

Hackenburg Lake

1. The lake has a surface area of 42 acres, a mean depth of 12 feet and a maximum depth of 38 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels fell below 1 mg/L at depths greater than 16 feet. This low dissolved oxygen, coupled with an observed high concentration of total phosphorus in the bottom waters of the lake indicate that internal loading of phosphorus from the sediments may be significant.

4. Chlorophyll a concentration in the lake was 3.8 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 2.3 meters.

6. The lake contained high concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 49 eutrophy points and is therefore classified as a Class II (intermediate water quality) waterbody. According to the Carlson Trophic State Index, the lake is eutrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems only account for less than 1 percent of the phosphorus and nitrogen loads to the lake.

Martin Lake

1. The lake has a surface area of 26 acres, a mean depth of 34 feet and a maximum depth of 56 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels fell below 1 mg/L at depths greater than 36 feet. This low dissolved oxygen, coupled with an observed moderate concentration of total phosphorus in the bottom waters of the lake indicate that internal loading of phosphorus from the sediments may be significant.

4. Chlorophyll a concentration in the lake was 3.5 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 4.2 meters.

6. The lake contained moderate concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 34 to 35 eutrophy points and is therefore classified as a Class II (intermediate water quality) waterbody. According to the Carlson Trophic State Index, the lake is classified as mesotrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems only account for less than 1 percent of the phosphorus load and 1.3 percent of the nitrogen load to the lake.

Messick Lake

1. The lake has a surface area of 68 acres, a mean depth of 21 feet and a maximum depth of 54 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels fell below 1 mg/L at depth greater than 16 feet. This low dissolved oxygen, coupled with an observed high concentration of total phosphorus in the bottom waters of the lake indicate that internal loading of phosphorus from the sediments may be significant.

4. Chlorophyll a concentration in the lake was 3.3 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 2.2 meters.

6. The lake contained high concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 39 eutrophy points and is therefore classified as a Class II (intermediate water quality) waterbody. According to the Carlson Trophic State Index, the lake is highly mesotrophic to slightly eutrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems only account for 1.2 percent of the phosphorus load and 1.6 percent of the nitrogen load to the lake.

Olin Lake

1. The lake has a surface area of 103 acres, a mean depth of 39 feet and a maximum depth of 82 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels never fell below 2 mg/L in the bottom waters. The dissolved oxygen were relatively high throughout most of the water column, which explains the low phosphorus levels observed in the bottom waters.

4. Chlorophyll a concentration in the lake was 1.2 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 3.5 meters.

6. The lake contained low to moderate concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 24 to 26 eutrophy points and is therefore classified as a Class I/II (highest to intermediate water quality) waterbody. According to the Carlson Trophic State Index, the lake is mesotrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses.

Oliver Lake

1. The lake has a surface area of 394 acres, a mean depth of 39 feet and a maximum depth of 93 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels fell below 1 mg/L at depths greater than 88 feet. Due to relatively high dissolved oxygen levels throughout most of the water column, total phosphorus concentrations were relatively low in the bottom waters of the lake.

4. Chlorophyll a concentration in the lake was 2.7 μg/L and the phytoplankton population was dominated by diatoms.

5. Secchi disk transparency was 2.7 meters.

6. The lake contained low to moderate concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 8 to 10 eutrophy points and is therefore classified as a Class I (highest water quality) waterbody. According to the Carlson Trophic State Index, the lake is classified as mesotrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems account for 5.2 percent of the phosphorus load and 5.9 percent of the nitrogen load to the lake.

Westler Lake

1. The lake has a surface area of 88 acres, a mean depth of 20 feet and a maximum depth of 33 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels fell below 1 mg/L at depths greater than 16 feet. This low dissolved oxygen, coupled with an observed high concentration of total phosphorus in the bottom waters of the lake indicate that internal loading of phosphorus from the sediments may be significant.

4. Chlorophyll a concentration in the lake was 6.0 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 1.1 meters.

6. The lake contained high concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 53 to 56 eutrophy points and is therefore classified as a Class III (lowest water quality) waterbody. According to the Carlson Trophic State Index, the lake is classified as eutrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems only account for 1.6 percent of the phosphorus load and 2.4 percent of the nitrogen load to the lake.

Witmer Lake

1. The lake has a surface area of 204 acres, a mean depth of 35 feet and a maximum depth of 54 feet.

2. For the study date, the lake was thermally stratified.

3. Dissolved oxygen levels fell below 1 mg/L at depth greater than 16 feet. This low dissolved oxygen, coupled with an observed high concentration of total phosphorus in the bottom waters of the lake indicate that internal loading of phosphorus from the sediments may be significant.

4. Chlorophyll a concentration in the lake was 6.7 μg/L and the phytoplankton population was dominated by bluegreen algae.

5. Secchi disk transparency was 1.1 meters.

6. The lake contained high concentrations of both nitrogen and phosphorus. Phosphorus was the limiting nutrient (that nutrient whose concentration controls algal growth).

7. By Indiana standards, the lake scored 56 to 58 eutrophy points and is therefore classified as a Class III (lowest water quality) waterbody. According to the Carlson Trophic State Index, the lake is classified as eutrophic.

8. Pollutant loading (nutrients and suspended solids) are primarily from agricultural land uses. Septic systems only account for 1.6 percent of the phosphorus load and 2.3 percent of the nitrogen load to the lake.

Recommendations

WATERSHED-WIDE RECOMMENDATIONS

The following recommendations are described in detail in Section 6.

1. A watershed management district serving the entire ten LaGrange County lakes watershed should be established. The watershed management district would be responsible for overseeing all activities that may impact the water quality of all of ten lakes. It is recommended that members of the South County LaGrange County Water Quality Commission (SCLCWQC) assist in the formation of this newly created watershed management district. Enforcement and taxation bodies would look to the watershed management district for guidance on watershed-related activities. A formal organization plan for the watershed management district should be drawn up immediately so that action can begin on management activities for the ten Indiana lakes. The watershed management district can be formed around existing state laws (i.e. conservancy district) or draft up its own by-laws. The advantage of forming a conservancy district is that the district would have taxing powers.

   The Board of Directors (or advisory committee) of the watershed management district should include all appropriate government representatives, other people who can offer valuable technical and planning expertise, and at least one representative from each of the ten lake associations. The functions of the watershed management district would be as follows: 1) coordination of effort among LaGrange and Noble Counties and the Town of Wolcottville to accomplish watershed and lake management activities, 2) provision of technical and advisory assistance to local governments, homeowners, businesses, developers, and farmers, 3) development of model programs and ordinances, including erosion and sedimentation ordinances for new construction and a stormwater runoff ordinance to control water quality and flooding, for the adoption by Nobel and LaGrange Counties 4) prioritization of watershed and lake management activities, which encompass the implementation of best management practices within the watershed, and further lake and watershed studies, and 5) financial management of lake and watershed programs, which includes the acquisition of state, federal and private funds to be used for various projects throughout the watershed.

   Another important function of the watershed management district would be to develop educational materials and conduct educational programs for regulatory people, school children, and the public at large. One important activity which should be part of the educational program is a "Watershed Watch" program, where volunteers actively participate in monitoring activities within the watershed that may have negative impacts on water quality. Educational fact sheets could be developed and distributed which describe potential pollutant sources (eroding land, gasoline, oil, or chemical spills, etc.), presents information on watershed and water quality protection, and gives a telephone number to contact if someone sees a possible problem.

The watershed management district would also be involved in land use planning activities which would protect or improve the water quality in the ten Indiana lakes. Such activities might include land acquisition, conservation easements, and land trusts.

2. There are some general watershed management guidelines which apply to all of the ten LaGrange County lake watersheds. Watershed management guidelines include the following: the implementation of agricultural best management practices (Ag BMP's), homeowner best management practices, wastewater management practices and stabilization practices for both roadways and streambanks. In addition, erosion control and stormwater runoff ordinances should be established within the boundaries of the ten LaGrange County lakes watershed.

3. Failing septic systems should be identified and action taken to repair or replace them. A wastewater treatment facility feasibility study should be initiated at Atwood Lake, where septic systems contribute an estimated 22 percent of the annual phosphorus load to the lake. Loading from septic systems is only a small percentage of the annual budgets on the remaining lakes (excluding Adams). It is important to note that while septic loading may contribute a small percentage of the nutrients to the lake when compared to the rest of the watershed, failing septic systems could be delivering high nutrient levels near shore, where plant growth is problematic. There is also the potential for bacterial contamination, due to the number of older systems located close to the lake, both in distance and in elevation.

4. The watershed management district should apply for funding through Section 319 of the Clean Water Act and IDNR "T by 2000" Lake Enhancement Program to implement agricultural best management practices (BMP's).

5. In order to assess the impacts of the County landfill on the water quality of Dove Creek, the watershed management district should investigate existing groundwater and stream water quality data near this landfill. Data may be available through IDEM. If insufficient water quality data is available, the watershed management district should collect stream samples from Dove Creek. At a minimum, stream samples should be collected from stations located upstream and downstream of the existing fill area during baseflow and stormflow conditions.

6. The use of benthic barriers for macrophyte control around private docks should be implemented wherever possible. This is a low-cost, effective alternative to using chemicals.

7. There are many areas within the ten LaGrange County lakes that can benefit from spot-dredging, particularly channel areas. These are presented in detail in Section 6.

8. The use of alum for nutrient inactivation and aeration are recommended for some lakes if land treatment fails to improve water quality in the lake.

LAKE SPECIFIC RECOMMENDATIONS

The following lake specific recommendations are <u>in addition</u> to those recommendations described above. For several of the lakes, nutrient inactivation and/or hypolimnetic aeration should be reevaluated after watershed best management practices (BMP's) have been implemented and lake water quality does not improve.

Adams Lake

Reevaluate nutrient inactivation as an in-lake management technique after the wastewater treatment facility has been operational for a number of years and lake water quality does not improve.

Atwood Lake

Investigate the feasibility of a wastewater treatment facility to reduce nutrient loadings from on-lot septic systems. Based on the pollutant budget, septic system loadings contribute a substantial amount of nutrients to the lake.

After implementing watershed BMP's, which includes the construction of a wastewater treatment facility (if feasible), reevaluate the use of hypolimnetic (bottom water) aeration and nutrient inactivation as in-lake management techniques if lake water quality does not improve.

Dallas Lake

There are no individual management techniques recommended for Dallas Lake. The watershed-wide lake and watershed management recommendations, as described above, will address the major water quality problems of Dallas Lake, which are aquatic plant control and sediment and nutrient loadings from the watershed.

Hackenburg Lake

There are no individual management techniques recommended for Hackenburg Lake. The watershed-wide lake and watershed management recommendations, as described above, will address the major water quality problems of Hackenburg Lake, which are aquatic plant control and sediment and nutrient loadings from the watershed.

Martin Lake

There are no individual management techniques recommended for Martin Lake. The watershed-wide lake and watershed management recommendations, as described above will, address the major water quality problems of Martin Lake, which are aquatic plant control and sediment and nutrient loadings from the watershed.

Messick Lake

After nutrient loadings are reduced within the watershed, the use of hypolimnetic (bottom water) aeration as in-lake management techniques should be reevaluated if lake water quality does not improve. In several lake channels, sediments may be removed via dredging to improve navigation.

Olin Lake

There are no individual management techniques recommended for Olin Lake. The watershed-wide lake and watershed management recommendations, as described above, will address the major water quality problems of Olin Lake, which are aquatic plant control and sediment and nutrient loadings from the watershed.

Oliver Lake

Sediments should be removed by dredging at the mouth of Dove Creek and the adjacent channels. By removing excessive amounts of sediments, navigation will be greatly enhanced.

Westler Lake

Reevaluate the use of hypolimnetic (bottom water) aeration as in-lake management techniques if watershed BMP's fail to improve lake water quality.

Witmer Lake

Reevaluate the use of nutrient inactivation as in-lake management techniques if watershed BMP's fail to improve lake water quality.

1.0 Project Description

1.1 Background

Adams, Atwood, Witmer, Westler, Dallas, Hackenburg, Messick, Martin, Olin, and Oliver Lakes are located in south central LaGrange County, in northeastern Indiana (Figure 1.1). Some of these lakes are often referred to as the Indian Lakes, a term which will be used to some extent in this report for simplicity's sake. The lakes share a common watershed in northeast Noble and southeast LaGrange Counties. The Little Elkhart Creek, is the main tributary to Witmer Lake. Adams and Atwood Lakes also drain into Witmer Lake. Witmer Lake flows to Westler Lake which empties into Dallas Lake. Hackenburg Lake collects flow from Dallas Lake and the three-lake chain of Martin, Olin and Oliver Lakes. Hackenburg Lake drains into Messick Lake, which is the last lake of the series. Water from Messick Lake flows into the North Branch of the Elkhart River. The North Branch joins the Elkhart River, then merges with the St. Joseph River at Elkhart, IN. The St. Joseph River flows through South Bend, northward into Michigan and on into Lake Michigan at St. Joseph.

The 56 square-mile watershed consists primarily of agricultural land interspersed with small towns, wetlands, and twenty lakes. Corn, soybeans, wheat, and forage are the main crops. There are numerous well-established Amish communities and small farms throughout the watershed. Wolcottville, population 880, is the largest town in the watershed and is located near Witmer Lake in LaGrange County.

Many of the lakes in this study have extensive shoreline development with close-packed small lots. Some shoreline areas have been channelized to increase waterfront land area available for development. Large campgrounds have shoreline sites and access at Atwood and Messick Lakes.

A few of the study lakes have little or no shoreline development; most notably Indiana Department of Natural Resource's Olin Lake Nature Preserve. Olin Lake is the largest lake in Indiana with undeveloped shoreline. Hackenburg and Martin Lakes also have large areas which remain undeveloped, primarily due to wetlands along the shore. There are extensive wetlands adjacent to and between a number of the lakes. In addition to the Olin Lake Nature Preserve, the watershed contains eight other registered Natural Areas under the IDNR program. All the natural preserve areas within the ten LaGrange County lakes watershed are listed in Table 1.1 along with their approximate size.

Of the ten Lagrange County lakes, Martin Lake, Olin Lake and Oliver Lake have plant and animal species which are classified as either special concern, threatened or endangered. For these lakes, state listed plant and animal species along with their respective status and record data are provided in Table 1.2. In Table 2.1, no federal status is given for any of the listed plant and animal species.

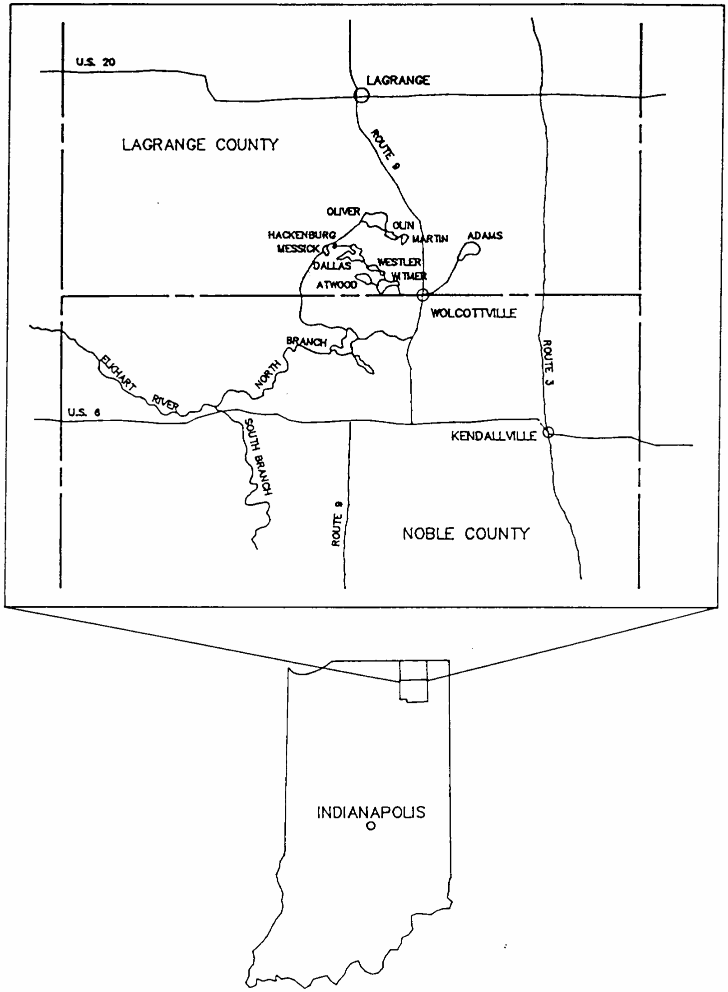


Figure 1.1	Location Map of South Central LaGrange County Lakes in Northeast Indiana

Table 1.1 Natural Preserve Areas in the Ten LaGrange County Lakes Watershed Area	
Natural Preserve Areas	**Area (acres)**
Olin Lake Nature Preserve	269
Svoboda Bog Natural Area	77
Nauvoo and Mud Lakes Natural Area	353
Tamarack Cemetery Natural Area	41
Holsinger Hole Natural Area	18
Quog Lake Natural Area	303
Hackenburg Lake Natural Area	272
Pond Lil Natural Area	76
Atwood Lake Natural Area	52

Water quality deterioration in many of the area's lakes first caused concern of residents and county officials in the late 1970's and during the 1980's. Excessive growth of algae and aquatic weeds are among the water quality problems identified in the LaGrange County lakes; high siltation rates, runoff from agriculture, and septic leachate are some of the causes. It is postulated that heavy development of the shoreline during the 1950's and 60's, further development and conversion of summer homes to year-round homes, and farming practices in the watershed have all had a significant impact on lake water quality.

Over the last decade, fish population surveys have been conducted by the Indiana Department of Natural Resources for the ten LaGrange County lakes. Generally as part of these surveys, aquatic macrophyte information is given. For all of the ten LaGrange County lakes, no serious impairments due to the presence of aquatic macrophytes were noted. The following paragraphs represents a summary of these fish population surveys. Adams Lake's fishery primarily consists of yellow perch and bluegills. In 1988, tiger muskies were introduced to the lake and it was recommended that the lake should be managed for tiger muskies (Hudson, 1989). Atwood Lake's fishery has an abundance of undersized bluegills and red ear sunfish and a relatively low number of largemouth bass. IDNR recommended total eradication of the population and the lake should be restocked with bluegills and largemouth bass (Hudson, 1988). Dallas Lake's fishery contains a healthy population of bluegills, largemouth bass and northern pike, and no recommendations were noted (Hudson, 1982a). Hackenburg Lake's fishery consists primarily of bluegills, black crappie, brown bullhead, largemouth bass and yellow perch. IDNR recommended that additional stockings of channel catfish be introduced (Hudson, 1984a). Witmer Lake's fishery primarily consists of bluegill, black crappie, yellow perch, and largemouth bass. IDNR recommended that channel catfish be stock in the lake to provide additional sport fishing opportunities (Hudson, 1982b). Westler Lake's fishery consists primarily of bluegill, black crappie, yellow perch, and largemouth bass. IDNR recommended that additional stockings of channel catfish be introduced (Hudson, 1984b). Oliver Lake's fishery consists of a variety of fish, such as, bluegill, yellow perch, largemouth bass, rock bass, black crappie, smallmouth bass, brown trout, lake trout, rainbow trout and northern pike. IDNR recommended that the lake should be managed for trout (Hudson, 1983). Olin Lake's fishery primarily consist of rock bass, largemouth bass, bluegill, and green sunfish. IDNR recommended that the lake be managed for trout (Hudson and James, 1983a). Martin Lake's fishery primarily consists of bluegill, rainbow trout, white sucker and largemouth bass. IDNR recommended that the lake be managed for trout (Hudson and James, 1983b). Messick Lake's fishery primarily consists of bluegill, largemouth bass, and yellow perch. No recommendations for the management of the lake's fishery were noted (Hudson, 1982c).

All of the lakes included in this study were included in the Indiana Lake Classification Surveys conducted by the Indiana Department of Environmental Management in mid-1970's (except Atwood Lake) and the late-1980's, and in a study conducted by the LaGrange County Health Department and LaGrange County Soil and Water Conservation District sponsored by the LaGrange County Commissioners and funded through the T by 2000 Lake Enhancement Program (Grant, 1988). Concern about the future of water quality in the lakes inspired cooperation among separate lake associations and resulted

Table 1.2
State Listed Species in Martin, Olin and Oliver Lakes

Lake	Genus/Species	Common Name	State Status	Record Date
Martin Lake	*Coregonus artedii*	Cisco or Lake Herring	SSC	1974
	Myriophyllum verticillatum	Whorled Water Milfoil	ST	1985
Olin Lake	*Potamogeton praelongus*	White-Stem Pondweed	ST	1968
	Najas marina	Holly-Leaved Naiad	WL	1982
	Utricularia cornuta	Horned Bladderwort	ST	1962
	Myriophyllum verticillatum	Whorled Water Milfoil	ST	1982
	Coregonus artedii	Cisco or Lake Herring	SSC	1972
Oliver Lake	*Coregonus artedii*	Cisco or Lake Herring	SSC	1974
	Nycticorax nycticorax	Black-Crowned Night Heron	SE	1986

Key:

WL - watch list
ST - threatened
SSC - special concern
SE - endangered

in the formation of the South Central LaGrange County Water Quality Commission. The South Central LaGrange County Water Quality Commission applied for a grant to include ten lakes in a feasibility study under the Indiana Lake Enhancement Program, administered by Indiana Department of Natural Resources Division of Soil Conservation as part of the overall "T by 2000" program. The grant was awarded on July 11, 1990.

1.2 Project Objectives

This study was conducted under the Indiana DNR "T by 2000" Lake Enhancement Program. It was designed in accordance with specific requirements of the Lake Enhancement Program, and with procedures used in Phase I Diagnostic-Feasibility studies conducted under state and federal Clean Lakes programs. A diagnostic-feasibility study is typically conducted in two stages. The diagnostic portion of the study is conducted to determine water quality conditions in the lake, identify existing problems, and determine the pollutant sources that are responsible for the observed problems. The feasibility aspect of the study involves the development of alternative restoration programs based on the results of the diagnostic study. These alternatives can include watershed management practices and in-lake restoration methods.

The primary objectives of the "T by 2000" Lake Enhancement Feasibility Study for the South Central LaGrange County Lakes were to identify the sources and magnitude of pollutants entering each lake and recommend specific management controls, and to develop and recommend a lake and watershed management program that is cost-effective, environmentally sound, and acceptable to the public.

2.0 Lake and Watershed Characteristics

2.1 Lake Morphology

Lake surface area, depth, volume, and watershed area is presented for each study lake in Table 2.1. Because of the chain arrangement of the lakes, their watershed areas are additive: Adams and Atwood drain into Witmer. Witmer flows to Westler which empties into Dallas. Hackenburg collects flow from Dallas and the three-lake-chain, Martin, Olin, and Oliver. The collected waters move on to Messick, the last lake in the series.

Table 2.1
Lake and Watershed Characteristics of the Study Lakes*

Lake	Surface Area (acres)	Depth (feet)		Volume (million gallons)	Watershed Area (acres)‡	Watershed to Lake Ratio
		Ave.	Max.			
Adams	308	25	93	2,506	3,351	10.9
Atwood	170	9	33	509	776	4.6
Witmer	204	35	54	2,290	22,889	112.2
Westler	88	20	33	577	24,083	273.7
Dallas	283	35	96	3,250	25,295	89.4
Martin	26	34	56	290	2,978	111.4
Olin	103	39	82	1,299	3,562	34.6
Oliver	394	39	93	4,991	6,947	17.6
Hackenburg	42	12	38	168	34,979	832.8
Messick	68	21	54	473	35,608	523.6

* Surface area, maximum depth, and volume from Indiana DNR bathymetric maps, prepared in cooperation with USGS, 1955 - 1977. Watershed area from planimetry of USGS 7.5 minute quadrangles.

‡ Watershed area includes lake surface area.

2.2 Benefits and Recreational Use of LaGrange County Lakes

2.2.1 Present Lake Uses

The LaGrange County Lakes provide recreational opportunities for residents of LaGrange and Noble Counties, and for tourists from cities and outlying areas in Indiana, Ohio, and Michigan. Many people spend their summers at lakeside cottages and campsites in the Indian Lakes area. Summer recreational activities include boating, fishing, swimming, and camping. Boating opportunities range from canoeing the shallow wetland areas to water skiing the slalom course on Dallas Lake. Boating regulations vary from lake to lake. In the winter, the lakes are used for ice fishing, ice boating, and skating.

The Indiana Department of Natural Resources maintains public access areas for parking and boat launch at Adams, Atwood, Witmer, Westler, Oliver, and Messick Lakes. IDNR Division of Nature Preserves owns and maintains the 269-acre Olin Lake Nature Preserve where there is a self-guided trail leading through marsh, swamp, forest, upland woods, and near open water. LaGrange County owns and operates two parks in the area: Atwood Lake Beach, a swimming beach on the north shore of Atwood Lake, and a recently acquired 45-acre YWCA park adjacent to Dallas Lake. Facilities presently include small bunk houses (which will not be reopened), a central dining hall, and swimming beach. The county plans to enlarge the swimming beach, install playground equipment and new rest room facilities, and anchor mooring buoys offshore.

2.2.2 Impairment of Recreational Uses

Recreational use of the Indian Lakes has been curtailed in recent years by nuisance blooms of algae and the growth of aquatic macrophytes. Shore fishing access has been restricted during July and August due to excessive weed growth snagging fish lines. Excessive plant growth has also decreased utilization of swimming beaches. Boating activities are curtailed in mid-summer because weeds entangle props. In some lakes, annual chemical treatments are used every year to control plant growth. Siltation is another problem in some near-shore areas, particularly near the mouths of some tributaries. During the summer, there are also aesthetic problems and odor from plant growth and rotting debris on shorelines. All of the above problems are restricting lake usage and limiting the recreational potential of the lakes.

2.3 Bathymetric Survey

For all ten Indiana lakes, bathymetric and sediment profile maps were developed as part of this study. Using a fathometer, both water and sediment depth data were collected via boat along transects in August of 1990. For the ten Indiana lakes, bathymetric and sediment profile maps are included in Appendix A. The maps show the location of the all transects along with their associated bathymetric and sediment profiles.

Along each transect, the maximum sediment depth and the lake depth corresponding to the maximum depth of sediment are shown Table 2.2. The above information was determined from the bathymetric and sediment profiles (Appendix A). In Table 2.2, the term "variable" simply means that the maximum sediment depth did not occur at one particular lake depth, but over a wide range of lake depths along the transect.

As shown in Table 2.2, the greatest amount of sedimentation has occurred in Atwood and Hackenburg Lakes along transects 1 and 2, respectively. For these lakes, approximately 11.0 feet of unconsolidated sediment has accumulated over the years. For Atwood Lake, transect 1 is oriented from south to north and is located near the western shoreline of the lake. Along the western shoreline of Atwood Lake, the primary land use is agriculture and this land is likely contributing excessive sediments to the lake via overland flow (runoff). In Hackenburg Lake, transect 2 extends from the eastern inlet (the channel between Dallas and Hackenburg Lakes) to the lake's outlet. The excessive sediment that has accumulated along this transect may be attributed to excessive sediment loadings from the outlet from Dallas Lake and/or the two tributaries, which enter the lake along the northern shoreline.

For the remaining eight lakes, the maximum depth of sediment ranged from 1.0 to 6.0 feet thick as shown in Table 2.2. Of these lakes, Martin and Messick recorded the second greatest amount of sediment accumulation along transects 1 and 2, and 1, respectively. For Martin Lake, excessive sedimentation may be attributed to inputs from two tributaries, which enter along the lake's eastern shoreline. As for Messick Lake, excessive sediments are likely credited to loadings from the northern tributary.

In addition to sediment profile comparisons, the bathymetry of transects (Appendix A) was compared to bathymetric maps developed cooperatively by the Indiana Department of Natural Resources (IDNR) and the United States Geological Survey (USGS) in 1951-1965. In general, lake depth profiles recorded in 1990 as part of this study agreed reasonably well with IDNR/USGS bathymetric maps.

Table 2.2 Bathymetric and Sediment Profile Summary for Ten Indiana Lakes			
Lake	**Transect Number**	**Maximum Depth of Sediment (feet)**	**Depth of Lake Above the Maximum Sediment Depth (feet)**
Adams	1	4.5	49
	2	3.0	23
Atwood	1	11.0	10
	2	3.0	33
Dallas	1	1.0	variable
	2	3.0	54
	3	3.0	75
	4	2.0	24-26
	5	2.0	variable
Hackenburg	1	3.5	36
	2	11.0	9
Martin	1	6.0	53
	2	6.0	55
	3	3.5	43-50

Table 2.2 (Continued) Bathymetric and Sediment Profile Summary for Ten Indiana Lakes			
Lake	**Transect Number**	**Maximum Depth of Sediment (feet)**	**Depth of Lake Above the Maximum Sediment Depth (feet)**
Messick	1	6.0	25
	2	3.0	54
	3	4.0	38
	4	3.0	38
Olin	1	5.0	58
	2	2.0	variable
	3	1.5	47
	4	4.5	42
Oliver	1	3.0	30-35
	2	3.0	75
	3	2.0	46
	4	3.0	45
	5	3.5	28
Westler	1	3.0	variable
Witmer	1	3.0	6
	2	4.0	20

2.4 Watershed Characteristics

The drainage basin for the ten LaGrange County lakes has an area of 35,608 acres (14,411 hectares) and lies entirely within the Northern Lakes Natural Region of Indiana (Homoya, 1985). This area is part of the Eastern Lake section of the Central Lowland physiographic province and is characterized by maturely dissected and glaciated ridges and lowlands, moraines, lakes, and lacustrine plains. Watershed boundaries and the locations of major tributaries are shown in Figure 2.2.

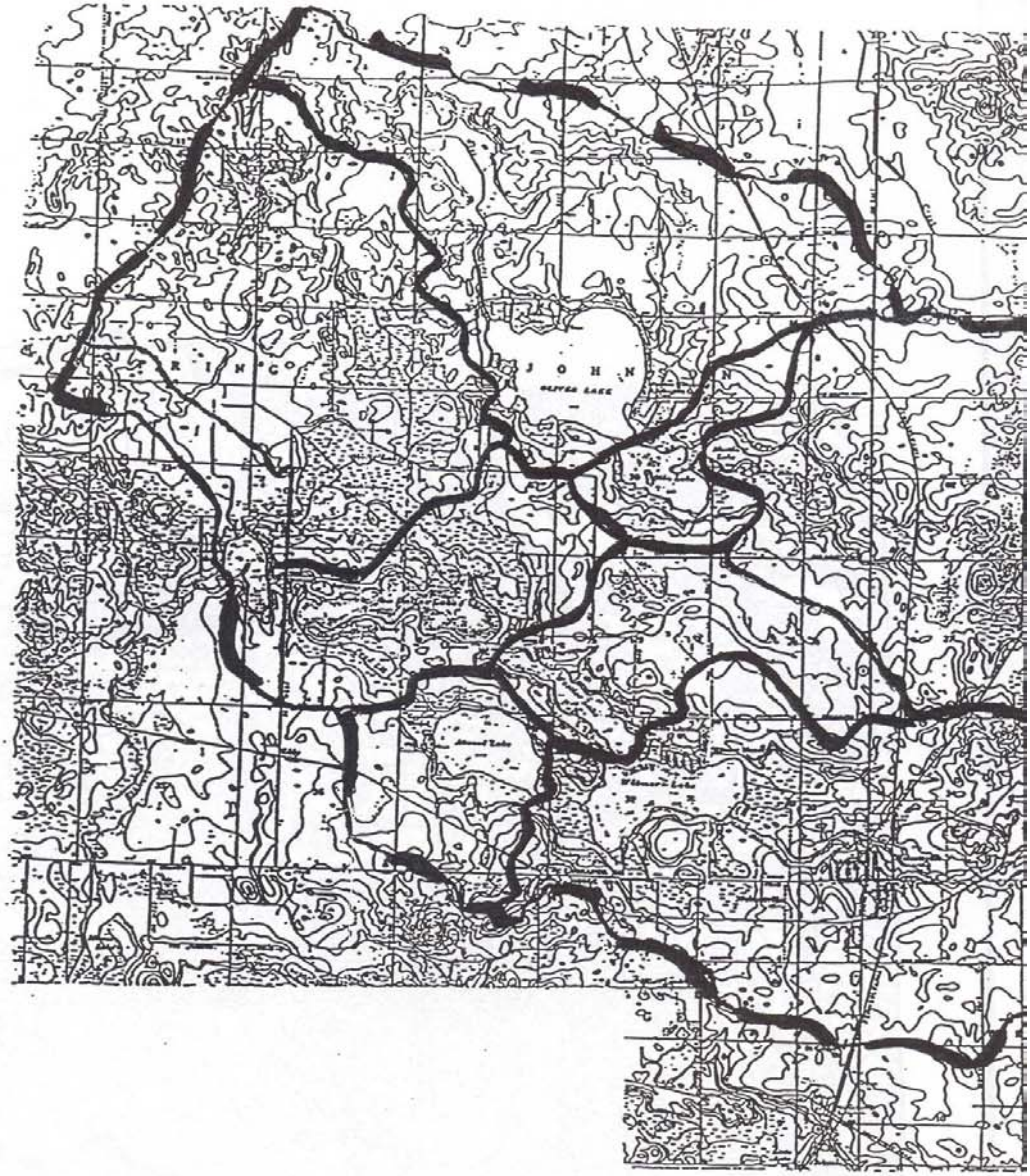
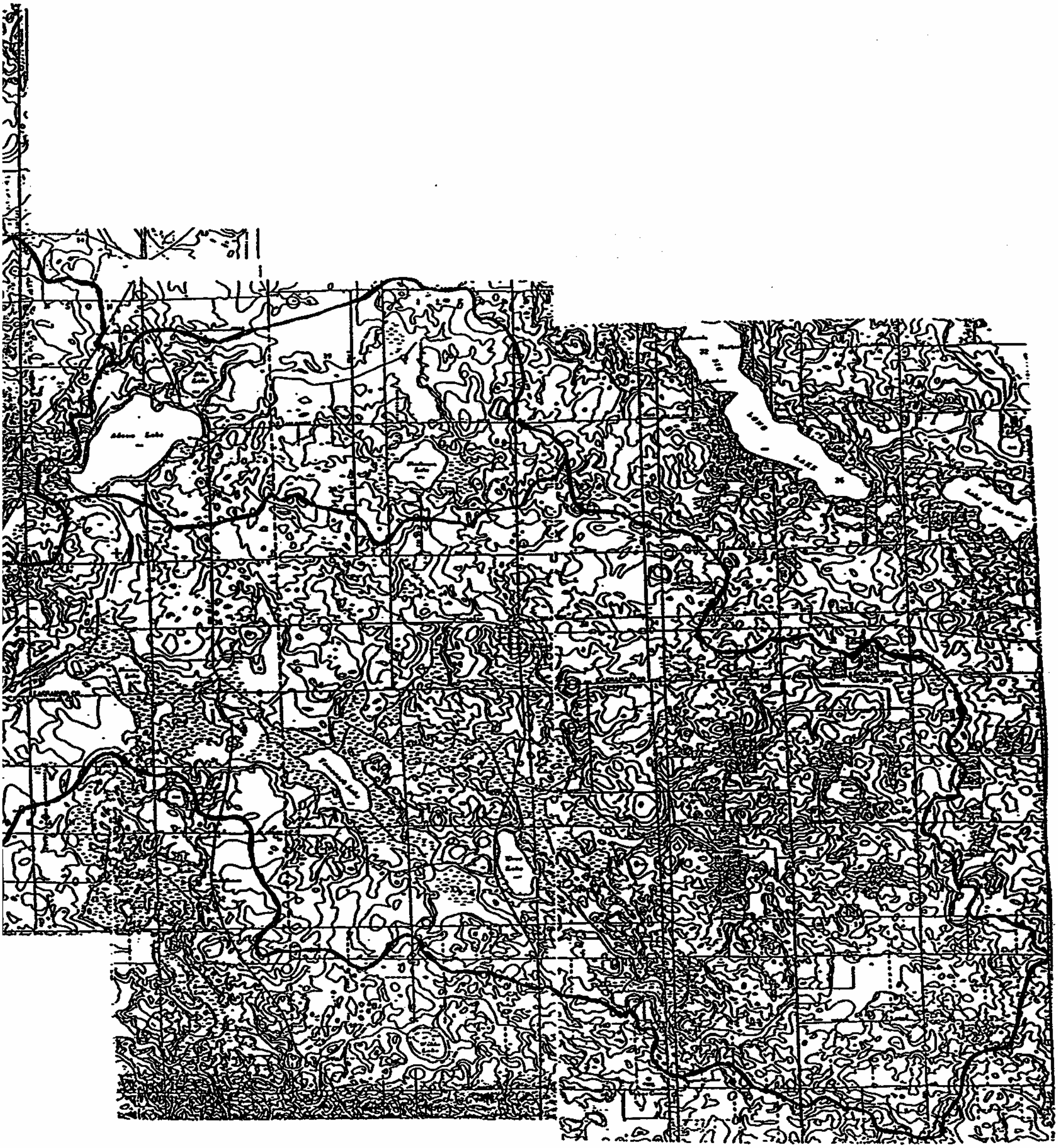


FIGURE 2.2

TEN LA GRANGE COUNT



JNTY LAKES WATERSHED

2.4.1 Topography

The topography of the ten LaGrange County lakes watershed is flat to rolling, with little topographic relief, and has complex drainage patterns with large wetlands. The maximum elevation in the watershed is 1070 feet MSL (mean sea level) at Sand Hill in the northeastern corner of Noble County and ranges down to 900 feet MSL at the outlet of Messick Lake.

2.4.2 Geology

Parent materials for soils in the ten LaGrange County lakes are unconsolidated surficial geologic deposits resulting from glacial activity in LaGrange and Noble Counties 10,000 years ago. The thickness of unconsolidated deposits ranges between 300 and 450 feet throughout the watershed (Gray, 1983). There are sharp differences in the properties of parent material, sometimes within short distances, because of the way glaciers deposited the material. The dominant parent materials in this area are glacial till, outwash deposits, lacustine deposits, and organic material. Glacial till is a mixture of coarse materials laid down by glaciers with a minimum of water action. Outwash deposits are size-sorted sand and gravel layers which have settled out of glacial meltwater. Lacustrine deposits are fine-grained layers which settled under still water. Organic material is deposited plant material which becomes muck (Hillis, 1980, McCarter, 1977).

Different shale types of the Devonian and Mississippian periods make up the underlying bedrock in the ten LaGrange County lakes watershed. Bedrock is older in the southern part of the watershed and younger in the north. Coldwater Shale is a gray shale underlying most of LaGrange County. A tongue of Ellsworth and Sunbury shales (gray, green and black shales) extends along the LaGrange/Noble County line from the west. A black shale called New Albany shale underlies most of Noble County (IGS, 1970).

2.4.3 Soils

The soils in the ten LaGrange County lakes watershed are primarily glacial till and outwash material interspersed with mucks. The dominant soil associations in the watershed are glacial till soils: the Wawasee-Hillsdale-Conover association in LaGrange County, characterized by nearly level to strongly sloping, well drained and somewhat poorly drained, moderately coarse textured and medium textured soils on till plains and moraines; and the Miami-Riddles-Brookston association in Noble County, characterized by well drained and very poorly drained, nearly level to moderately steep, deep soils that have a moderately fine textured subsoil on uplands. There are smaller areas dominated by outwash material: the Fox-Oshtemo association, southeast of Wolcottville in Noble County, and the Boyer-Oshtemo association in Wolcottville and immediately surrounding the lakes Witmer, Westler, Dallas, Messick, and part of Adams. Nearly level, very poorly drained muck soils (the Houghton-Adrian association), typically supporting wetland vegetation, surround Hackenburg Lake, extend southwest toward Messick Lake and northeast to the shorelines of Oliver, Olin, and Martin Lakes. In Noble County the muck soils belong to the Houghton-Edwards-Adrian association, and are found adjacent to Cree and Tamarack Lakes and along the streambed of Little Elkhart Creek (Hillis, 1980, McCarter, 1977).

Erosion is a hazard on sloping and steep areas in most of the dominant till soils (Miami, Riddles, Wawasee, and Hillsdale) and the outwash plains soils (Boyer, Oshtemo, and Fox). Some of the dominant well-drained soils are severely limited for septic tank absorption fields because of seepage and possible groundwater contamination (Oshtemo). Many of the dominant poorly drained soils are severely limited for use as septic tank absorption fields due to wetness, ponding, and permeability (Adrian, Houghton, Conover,and Edwards).

As seen in the AGNPS (Agricultural Nonpoint Source) modeling results (Appendix G), large portions of the ten LaGrange County lakes contain soils which are highly erodible. Below is the percentage of highly erodible soils in each of the ten lake's direct watershed areas.

For the majority of the direct watersheds, the highest average soil erodibility factor (k) (derived from AGNPS) was 0.28. The Witmer Lake direct watershed had a highest average k factor of 0.38, with 33 percent of the watershed having a k factor greater than or equal to 0.30. The Atwood Lake direct watershed had a highest average k factor of 0.32, with 7 percent of the watershed having a k factor greater than or equal to 0.30. The percentage of relatively highly erodible soils, with k factors greater than or equal to 0.25 was calculated for each direct watershed and the results are shown below.

Adams	44 %	Messick	28 %
Atwood	44 %	Olin	46 %
Dallas	22 %	Oliver	51 %
Hackenburg	20 %	Westler	36 %
Martin	32 %	Witmer	57 %

2.4.4 Groundwater

The large aquifer beneath the ten LaGrange County lakes watershed is stored in sand and gravel of the Pleistocene age. Wells are relatively shallow (40 to 100 feet, with water levels 3 to 20 feet below land surface datum. The water is hard (200 to 300 milligrams per liter as calcium carbonate) with a fairly high iron content of 0.4 to 0.7 milligrams per liter (Glatfelter et al., 1988). These characteristics result in scale formation on heating utensils, greater soap requirements for cleaning, and reddish discoloration; however no adverse health effects would be expected from these levels of hardness or iron.

There has been some concern about nitrate levels in wells within the ten LaGrange County lakes watershed. High levels of nitrate in well water indicate contamination from septic systems and agricultural fertilizers and can cause health problems, such as infant cyanosis ("blue baby"). The LaGrange County Health Department has tested numerous wells within the watershed. So far, only a few contained nitrates above the level considered safe for human and animal consumption, but further and more extensive testing will yield a more complete picture of groundwater nitrate contamination within the watershed.

2.4.5 Land Use

In the ten LaGrange County lakes watershed, the majority of the land is classified as agriculture as shown in Table 2.3. Agricultural lands accounted for 75.7 percent (26,951 acres) of all land uses within the watershed. To further expand on this category, row crop planting and pasture land practices accounted for approximately 70 and 30 percent of all agricultural land uses, respectively. Therefore, row crop and pasture land practices were estimated at 18,893 and 8,097 acres. Information regarding agricultural land use practices for each lake's direct watershed was obtained from the Soil Conservation Service (SCS) for both LaGrange and Noble Counties.

Other major land types are also shown in Table 2.3. Forest land and wetlands were estimated at 16.1 percent (5,735 acres), and the combination of the ten lakes plus other lakes accounted for 5.6 percent (2,018 acres). For the entire ten lakes watershed, only 2.5 percent (904 acres) of the land is classified as developed (residential/urban).

For the entire ten LaGrange County lakes watershed, various land types were determined by planimetry of a land use map. The land use map was constructed by overlaying topographic maps over aerial photographs, thereby allowing various land types to be delineated. Aerial photographs and topographic maps were obtained from Agriculture Conservation and Stabilization Service (ASCS) for LaGrange County and the United States Geological Survey (USGS), respectively.

Table 2.3 Land Use for the Entire Ten Indiana Lakes Watershed*		
Land Types	**Area (acres)**	**Percent (%)**
Ten LaGrange Co. Lakes	1,686	4.7
Other Lakes	332	1.0
Wetlands	3,229	9.1
Residential/Urban	904	2.5
Forest	2,505	7.0
Agriculture	26,951	75.7
Total	**35,608**	**100.0**

* Land use areas obtained by planimetry of land use map. Land use map was developed by F.X. Browne and Associates, Inc. and was based on aerial photographs (1989) obtained from the Agriculture Conservation and Stabilization for LaGrange County and the and topographic maps obtained from the United States Geological Survey.

2.5 Population and Socio-Economic Structure

The Indian Lakes provide recreational opportunities for residents of LaGrange and Noble Counties (combined population approximately 60,000) and other area residents. Public access is readily available through IDNR public access sites and LaGrange County parks.

LaGrange and Noble Counties are rural in nature with little overall change in land use over the years. The population growth rate is gradually increasing in Lagrange County, from a 13 percent increase between 1950 and 1960 to an estimated 24 percent increase between 1970 and 1980. Most of the growth areas are in towns or adjacent to the lakes.

Occupations of permanent residents within the watershed are primarily associated with agriculture. Some residents are employed by industries in nearby towns. There are several trailer and trailer related factories, recreational vehicle factories, and tool factories nearby. There is a concentration of Amish families in the lower part of the watershed, near Oliver, Hackenburg and Messick Lakes.

2.6 History

Early inhabitants of northern Indiana were the Potawatomi Indians ("People of Fire"), an Algonquin linguistic family closely associated with the Chippewa and Ottawa. In the late 1700's, the Prairie Potawatomi moved into lower Michigan and northern Indiana while the Forest Potawatomi remained in the forests of northern Wisconsin and upper Michigan. Forests, swamps, and lakes in the area provided plentiful supplies of fish, game, herbs, roots, and seeds (Wolfe, 1989).

The first white settlers arrived in the area in the 1820's and 30's. The first settlement in LaGrange County was near Howe where the Potawatomi Indians had established a village on the Pigeon River. LaGrange County was established in 1832. In 1838, the United States government organized a volunteer militia to force-march the Potawatomi Indians from northern Indiana to the valley of the Osage River in Kansas. The first Amish people arrived in the area in the early 1840's from Somerset County, Pennsylvania.

The LaGrange County lakes have been valued for their beauty, fishing potential, and recreational opportunities since the time of the Indians. The History of La Grange County (1882) refers to the LaGrange County lakes: "All of these picturesque little lakes, if joined together, would only form a water area of about seven square miles, but scattered about as they are, with beautiful natural surroundings, and filled with fish, such as bass, pickerel, perch, sunfish, catfish, and the resort of innumerable feathered game, they are of great value, and a source of much recreation. Many of the lakes, however, are becoming depopulated of their finny habitants, and every disciple of gentle Isaac Walton should urge some measure to restore their former attractiveness in this respect." Thus, there was interest in lake restoration for the LaGrange County lakes in 1882!

The lakes were threatened for a period in the early 1900's when farmers wishing to cultivate land near the lakes wanted to construct drainage systems near the lake outlets which would lower lake water levels, and would have resulted in stagnant ponds rather than flow-through systems. Because of this threat, legislation was enacted in 1905 to protect Indiana's fresh water lakes. It became unlawful to cut into or change lake banks in any way so as to lower water level, and drains could not be located so close to any lake covering ten or more acres that they would lower the water level of the lake (Hanan, 1928). A Primer on Lake Ecology and Glossary of Lake and Watershed Management terms are provided in Appendix B and Appendix C, respectively, to aid the reader in understanding the following discussions.

3.0 Water Quality

3.1 Monitoring Program

In order to assess the water quality of Adams, Atwood, Dallas, Hackenburg, Martin, Messick, Olin, Oliver, Westler and Witmer lakes located in LaGrange County, water samples were collected from the upper waters (epilimnion) and bottom waters (hypolimnion) in August 1990. In accordance with the procedures established by the Indiana Department of Environmental Management (IDEM), samples were collected at the deepest part of the lakes during the summer stratification period. Water quality samples were analyzed for all parameters included in the IDEM Eutrophication Index and some general water quality parameters as shown in Table 3.1. Sampling locations for lake water, stream water and lake sediment are shown in Figure 3.1. Water quality data is presented in Appendix D.

Table 3.1
Parameters Analyzed in Lake Water Samples

Soluble orthophosphate	Alkalinity
Total phosphorus	Secchi disk transparency
Ammonia nitrogen	Light intensity
Total Kjeldahl nitrogen	Dissolved oxygen
Nitrate + nitrite nitrogen	Temperature
Total suspended solids	Phytoplankton
Conductivity	Chlorophyll a
pH	

For each lake, secchi depth (transparency), light intensity, dissolved oxygen profiles, and temperature profiles were recorded. Water samples from the upper sunlit waters (photic zone) were collected for the analysis of chlorophyll a for the determination of algal biomass. Two five-foot algal tows were conducted at each sampling station, one from the five foot level to the lake's surface and one through the thermocline, for the determination of phytoplankton species (to genera).

The above data are typical of those used by the Indiana Department of Environmental Management for their lake classification studies and also includes additional information required by the U.S. EPA for diagnostic/feasibility studies. This data has been shown to be sufficient to provide the necessary information to evaluate most lakes. The data has provided information on lake stratification, oxygen regime, water transparency, nutrients, general water chemistry, and lake trophic state. Trophic state indices for each lake were calculated using both IDEM procedures and the Carlson's (1977) trophic state index.

Secchi depth was determined using an 8-inch (20 cm) black-white Secchi disk. Light intensity was measured by using a Lycor photometer. Water samples were collected using a horizontal alpha water sampler. Dissolved oxygen and temperature profiles were measured using a YSI meter. Phytoplankton samples were collected using a "birge style" closing net with a 80 μm net mesh size and a mouth diameter of 5 inches (13 cm).

Samples for phytoplankton analyses were preserved in the field with 7.0 mL of Lugol's solution per liter. Another 3 mL of Lugol's solution was added before storage in a refrigerator. Algal cells were identified and counted using a Sedgewick-Rafter counting chamber and a microscope equipped with a Whipple Grid.

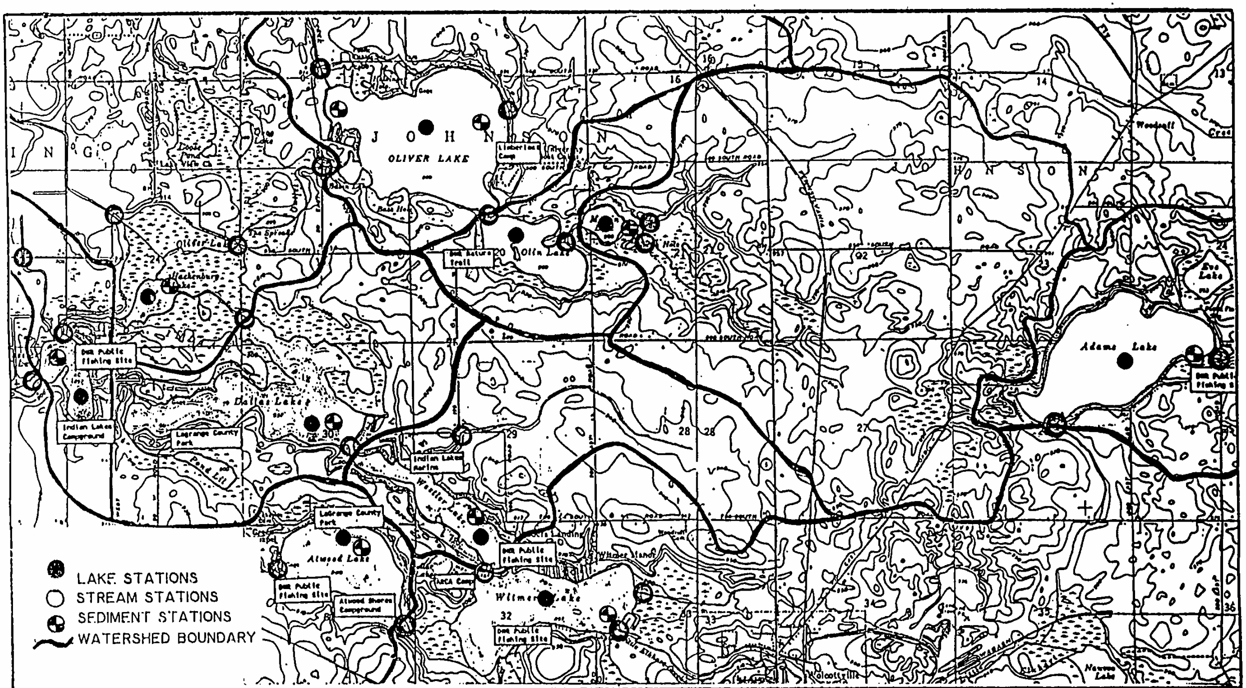


FIGURE 3.1

LOCATION OF LAKE, STREAM AND SEDIMENT SAMPLING STATIONS

3.2 Quality Assurance/Quality Control Procedures

3.2.1 Introduction

For this study a quality control program was performed in order to insure that the equipment and procedures being used in a study produce results that are both precise and accurate. Precision was monitored by performing duplicate analyses on selected samples. Accuracy was monitored by analyzing spiked samples and special quality control samples having known concentrations of various parameters.

All laboratory procedures were performed in accordance with *Standard Methods for the Examination of Water and Wastewater*, 17th Edition; *Methods for Chemical Analysis of Water and Wastes* (EPA-600/4-79-020); and *Handbook for Analytical Quality Control in Water and Wastewater Laboratories* (EPA-600/4-79-019). Results of the quality control program were recorded and were reviewed and evaluated.

The quality control/quality assurance procedures used in this study are as follows: (1) equipment calibration in accordance to manufacturer's recommendation, (2) standardization curves for all forms of nitrogen and phosphorus, (3) control charts established for all forms of phosphorus and nitrate/nitrite standards, (4) spiked sample analysis, (5) EPA reference sample analysis, (6) duplicate sample analysis, and (7) field split sampled analysis.

3.2.2 Parameters and Procedures

The following is a list of parameters and the procedures used for each:

Parameter	Procedure
pH	Standard Methods 4500-H^+ B
Alkalinity	EPA 310.1
Dissolved Oxygen	Standard Methods 4500-O C
Total Phosphorus	Standard Methods 4500-P B,E
Soluble Orthophosphorus	Standard Methods 4500-P B,E
Total Kjeldahl Nitrogen	Standard Methods 4500-N_{org} C
Nitrate/Nitrite	Standard Methods 4500-NO_3 E
Ammonia	Standard Methods 4500-NH_3 F
Total Suspended Solids	Standard Methods 2540 D
Chlorophyll a	Standard Methods 10200H-2
Conductivity	Standard Methods 2510 B

3.3 Chemical and Biological Interactions

Existing water quality in a lake is determined by numerous chemical, physical, and biological factors. The amount of nutrients and sediments delivered to a lake via its tributaries is a major factor affecting water quality. Variations in ambient temperature and sunlight are also important factors.

Nutrients (nitrogen and phosphorus) and suspended solids enter lakes from upstream tributaries and direct runoff from land adjacent to the lakes. As water enters the lake its velocity decreases, resulting in sedimentation of suspended solids. A portion of the phosphorus entering the lake is bound to sediment particles (referred to as particulate phosphorus), and this portion gradually settles. Very small sediment particles, such as clays, resist sedimentation and may pass through the lakes without settling.

Phytoplankton (algae) and rooted plants absorb available nutrients and convert them into plant material. The most readily available form of phosphorus, used by plants and algae, is dissolved orthophosphate. Dissolved orthophosphate is analytically determined as dissolved reactive phosphorus (DRP), which can also include hydrolyzable particulate and organic phosphorus. The inorganic forms of nitrogen, ammonia (NH_3-N) and nitrate (NO_3-N), are the forms most available to support the growth of aquatic life. Concentrations of dissolved orthophosphate and inorganic nitrogen are usually low in lakes since they are quickly taken up by plants and algae.

Aquatic plants (macrophytes) and algae can also affect concentrations of other chemical species in water. For example, in the photosynthetic process, carbon dioxide, a weak acid, is removed from the water and oxygen is produced, resulting in increased pH and dissolved oxygen levels.

Interactions among biological communities (the food web) greatly affect levels and cycling of nutrients, such as phosphorus, nitrogen and carbon in lakes. Energy from the sun is captured and converted to chemical energy via photosynthesis in aquatic plants, which forms the base of the food web as shown in Figure 3.2. Energy and nutrients, now tied up in organic molecules, travel through the different levels of the

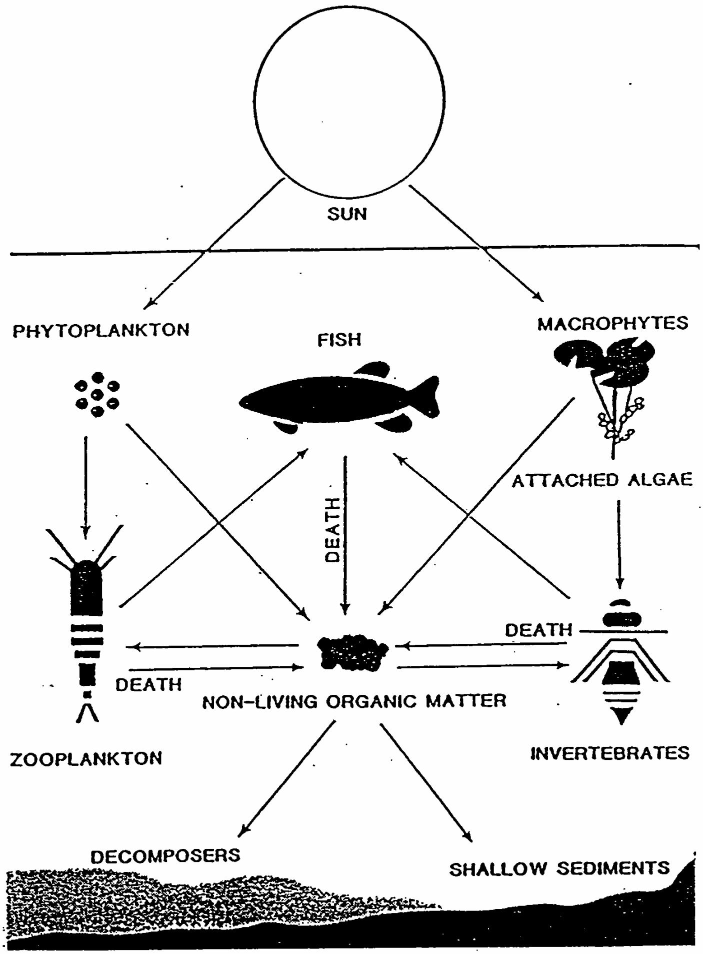


Figure 3.2	The Aquatic Food Web

food web. Small aquatic animals (zooplankton and invertebrates) graze upon algae and plants. Larger invertebrates and fish then consume the grazers. Energy at upper levels of the food web is derived from the breakdown of organic molecules in the process known as respiration. Respiration and decomposition processes consume oxygen in the water column and in lake sediments. The larger organic waste products of the food web organisms, together with their remains after death, comprise detritus, which settles to the bottom of the lake and becomes part of the sediment. Bacteria and fungi (decomposers) utilize the energy in this material, converting organic molecules to inorganic nutrients which are once again available for use by plants and algae. Unused organic material accumulates in the sediments. Energy can become blocked in lower levels of the food web instead of flowing smoothly through it, because many of the algae and aquatic plants found in highly eutrophic lakes are also the ones least favored by grazers.

Physical, chemical, and biological characteristics for ten lake projects in LaGrange County are discussed in the following sections.

3.4 Lake Water Quality Data

3.4.1 Temperature and Dissolved Oxygen

Usually at the beginning of summer, temperate lakes develop stratified layers of water, where warmer waters are near the lake's surface (epilimnion) and colder waters are near the lake's bottom (hypolimnion). As temperature differences become greater between these two water layers, the resistance to mixing will also increase. Under these circumstances, the surface waters are usually oxygen rich due to photosynthesis and direct inputs from the atmosphere, while the bottom waters become more depleted due to the decomposition of organic matter and isolation from oxygen sources.

As shown in Figure 3.3 through 3.7, all ten lakes appeared to be well stratified in August 1990. For Adams, Atwood, Hackenburg, Messick, Westler and Witmer Lakes, dissolved oxygen levels were near or less than 1 mg/L at depths exceeding 16 feet (5 meters). At Dallas Lake, dissolved oxygen concentrations fell below 1 mg/L at a depth of 20 feet (6 meters), but concentrations approached 2 mg/L at depths ranging from 43 to 52 feet (13 to 16 meters). This slight increase in dissolved oxygen levels at 43 to 52 feet may have been attributed to suspended algae, where photosynthesis exceeded respiration rates.

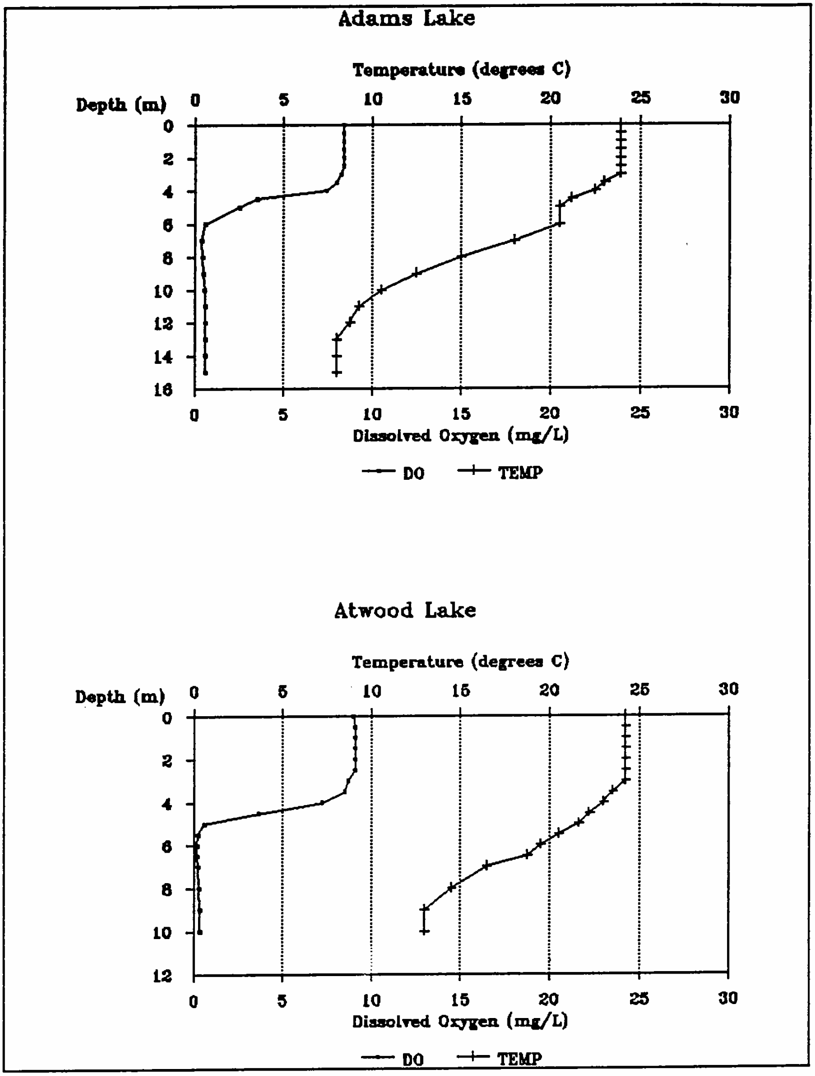


Figure 3.3 Dissolved oxygen and temperature profiles for Adams and Atwood Lakes

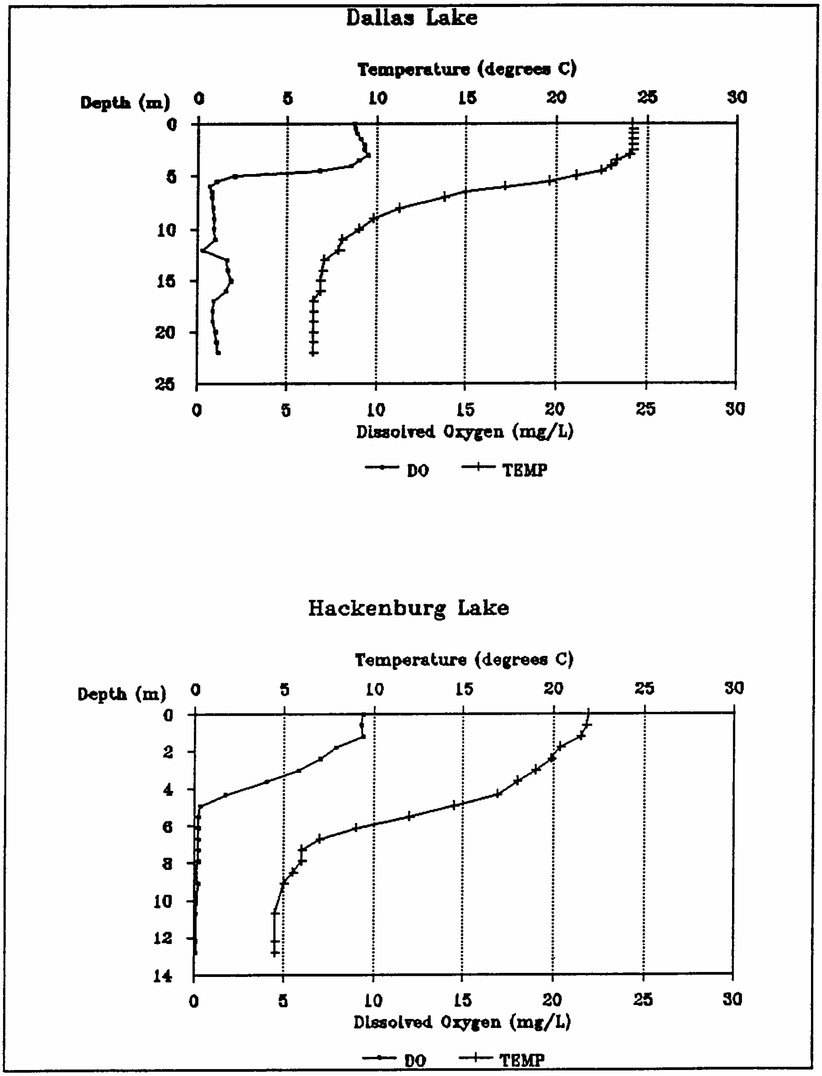


Figure 3.4 Dissolved oxygen and temperature profiles for Dallas and Hackenburg Lakes

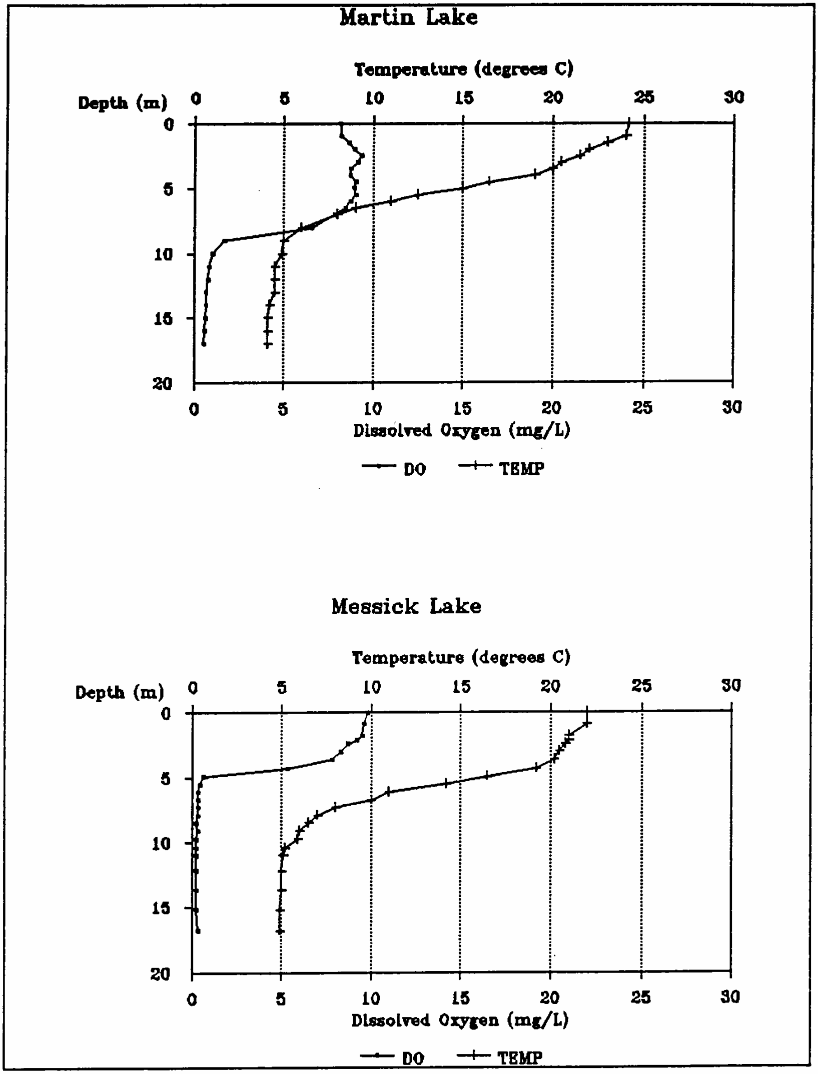


Figure 3.5 Dissolved oxygen and temperature profiles for Martin and Messick Lakes

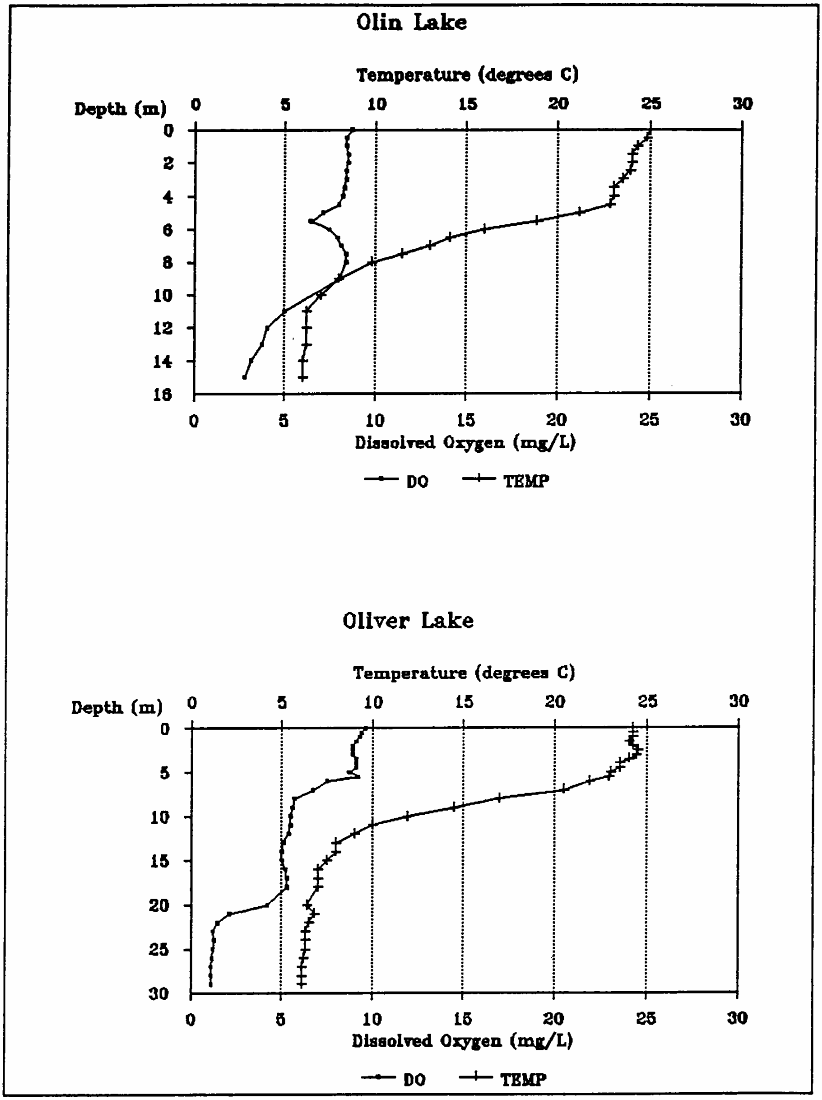


Figure 3.6 Dissolved oxygen and temperature profiles for Olin and Oliver Lakes

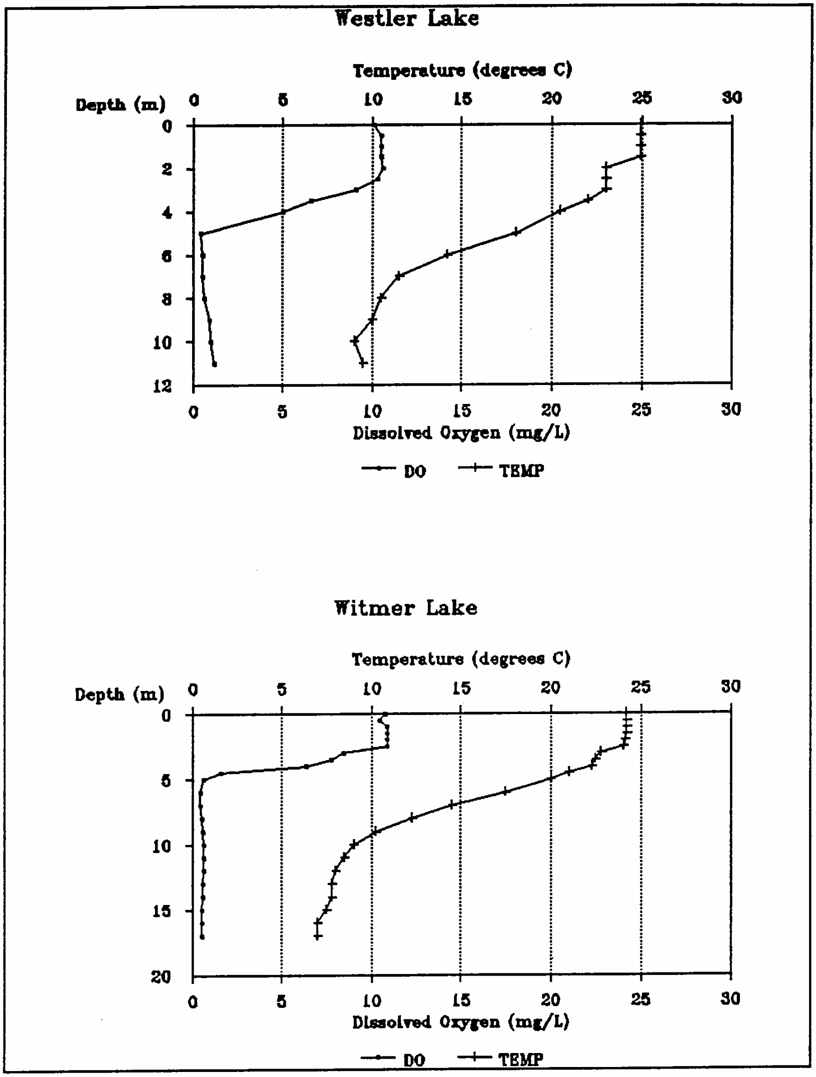


Figure 3.7 Dissolved oxygen and temperature profiles for Westler and Witmer Lakes

Dissolved oxygen concentrations for Martin, Oliver and Olin Lakes were higher than the lakes cited above. For Martin and Oliver Lakes, dissolved oxygen concentrations were below 1 mg/L at depths greater than 36 and 88 feet (11 and 27 meters), respectively, while concentrations never fell below 2 mg/L in Olin Lake.

In general, dissolved oxygen levels below 4 mg/L may impair some forms of aquatic life and extremely low dissolved oxygen conditions promote the release of phosphorus bound in lake sediments, thereby providing more nutrients available for algal growth.

3.4.2 Alkalinity, pH and Conductivity

Alkalinity and pH are interrelated. pH is a term used to express the intensity of the acids or bases in the water in terms of hydrogen ion concentration. It is important because most chemical and biological reactions are controlled or affected by pH. The alkalinity of water is a measure of the buffering capacity, or the capacity of the water to neutralize acids. Alkalinity of neutral waters is due primarily to salts of weak acids such as bicarbonates, carbonates, borates, silicates and phosphates. Although many materials contribute to the alkalinity of water, most of the alkalinity in natural waters is caused by hydroxides, carbonates and bicarbonates. The bicarbonates represent the major form of alkalinity because they are formed by the action of carbon dioxide with basic materials in soil.

In lake ecosystems, interactions between hydrogen ions and buffering ions occur when phytoplankton use carbon dioxide in their photosynthetic activity. As carbon dioxide is removed by algae, the pH of the water increases, thereby transforming both carbonate and bicarbonate forms of alkalinity into carbon dioxide, which is used by algae for further growth. Therefore, carbonate indirectly acts as a food source for the algae.

Conductivity refers to the ability of a water sample to conduct an electric current. Conductivity is directly related to the ionic species present in solution, which include both alkalinity and pH. Conductivity values vary greatly for both surface and groundwater, where values range from 50 to 1500 micromhos/cm (APHA, 1989).

Alkalinity, pH, and conductivity values for all ten lakes are shown in Table 3.2. Alkalinities ranged from 110 to 252 mg/L. With the exception of Martin Lake, bottom concentrations exceeded concentrations measured for the surface waters. Differences between alkalinities may be the result in differences in photosynthetic activity, where photosynthesis is generally higher at the epilimnion. Also, lake sediments can contribute alkalinity to the bottom waters, particularly when dissolved oxygen concentrations are low. The alkalinity values reported in Table 3.2 may be classified as "moderate", thereby providing sufficient protection to acidic inputs, such as "acid rain".

In all ten lakes, surface water pH values exceeded values recorded for the bottom waters. Higher values in the surface waters are probably due to high amounts of photosynthetic activity, where pH increases as photosynthesis increases. The reported pH values ranged from 7.3 to 8.7. Values of pH between 6 and 9 are considered normal for lake systems.

Conductivity values were higher in the bottom waters than in the surface waters of all ten lakes. High hypolimnetic conductivities are related to low pH values and high alkalinities. The conductivity values for the ten lakes are typical to values reported for potable water sources.

Table 3.2
Alkalinity, pH and Conductivity at Ten Lakes in LaGrange County

Lake Zone	Alkalinity, Total (mg/L as $CaCO_3$)		pH (standard units)		Conductivity (micromhos/cm)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
Adams	128	152	8.5	7.6	349	399
Atwood	110	152	8.7	7.5	256	333
Dallas	170	200	8.5	7.6	407	493
Hackenburg	174	228	8.3	7.4	412	533
Martin	230	164	8.3	7.6	545	625
Messick	166	214	8.4	7.5	415	509
Olin	174	208	8.3	7.6	448	503
Oliver	158	184	8.4	7.7	411	464
Westler	168	252	8.5	7.3	405	543
Witmer	170	216	8.5	7.6	407	494

3.4.3 Transparency, Total Suspended Solids, Chlorophyll a, and Phytoplankton

The transparency, or clarity, of water is most often reported in lakes as the Secchi disk depth. This measurement is taken by lowering a circular white or black-and-white disk, 20 centimeters in diameter, into the water until it is no longer visible. Observed Secchi disk depths range from a few inches in very turbid lakes to over 130 feet in the clearest known lakes (Wetzel, 1975). Therefore, greater Secchi disk depths represent better water transparency. Although somewhat simplistic and subjective, this testing method probably best represents the conditions which are most readily visible to the common lake user.

Total suspended solids is a measure of the amount of particulate matter in the water column. Suspended solids are comprised of both organic matter, such as algae, and inorganic material, including soil particles and clay minerals. Therefore, total suspended solids concentrations are directly related to transparency.

Chlorophyll a is a pigment which gives the green color to all plants. Its function is to convert sunlight to chemical energy in the process known as photosynthesis. Water samples containing algae can be treated to extract chlorophyll a from algal cells for analysis. Chlorophyll a constitutes about 1 to 2 percent of the dry weight of planktonic algae, so the amount of chlorophyll a in a water sample is an indicator of phytoplankton biomass.

Phytoplankton are microscopic algae which have little or no resistance to currents and live free-floating and suspended in open water. Forms may be unicellular, colonial or filamentous. As photosynthetic organisms (primary producers), they form the base of aquatic food chains and are grazed upon by zooplankton and herbivorous fish. A healthy lake should support a diverse assemblage of phytoplankton, in which many algal classes are represented. Excessive growth of a few species, particularly blue-green algae, is usually undesirable. Such growths can cause oxygen depletion in the water at night, when the algae are respiring but not photosynthesizing. Oxygen depletion can also occur after an algal bloom when bacteria, using dead algal cells as a food source, grow and multiply.

As shown in Table 3.3, transparency, total suspended solids, chlorophyll a concentrations, and phytoplankton counts were determined for all ten lakes. Transparency was the highest in Martin Lake and Olin Lake and the lowest in Westler Lake and Witmer Lake. Transparency values less than 1.5 to 2.0 meters generally indicate eutrophic conditions (EPA, 1980). Witmer Lake and Westler Lake recorded the highest Chlorophyll a levels at 6.0 and 6.7 μg/L, respectively, while Olin recorded the lowest value at 1.2 μg/L. Chlorophyll a concentrations greater than 6 to 10 μg/L are an indication of eutrophic conditions (EPA, 1980).

Total suspended solids concentrations were the highest in Witmer Lake and Westler Lake and the lowest in Olin Lake and Adams Lake. Phytoplankton counts were the highest in Witmer Lake and Hackenburg Lake and the lowest in Olin Lake, Atwood and Oliver Lakes.

Excessive growths of some species of algae, particularly members of the blue-green group, may cause taste and odor problems, release toxic substances to the water, or give the water an unattractive green soupy or scummy appearance. For each lake, the percent of blue-green algae present in the phytoplankton counts are shown in Table 3.4. With the exception of Oliver Lake, blue-green algae (Cyanophyta) were the dominant form of algae in August 1990. For a complete listing of the phytoplankton identified in each of the ten LaGrange County Lakes, refer to Appendix D.

3.4.4 Nutrient Concentrations

Phosphorus and nitrogen compounds are important for the growth of algae and other aquatic organisms in the aquatic food web. Both total phosphorus and orthophosphorus were analyzed for the ten lakes. Total phosphorus represents the sum of all phosphorus including live algae, dead algae, other microorganisms, organic phosphorus, polyphosphates and orthophosphates. Soluble orthophosphate is the phosphorus form that is most readily available for algal uptake. Total Kjeldahl nitrogen and nitrate plus nitrite nitrogen were also analyzed. Total Kjeldahl nitrogen is the sum of organic nitrogen and ammonia. In aquatic ecosystems, ammonia and nitrate are the most available forms for algae and other aquatic organisms.

In general, limited amounts of algae are desirable in lake ecosystems. Algal growth depends on a variety of nutrients, including macronutrients such as phosphorus, nitrogen, and carbon, and trace nutrients, such as iron, manganese, and other trace minerals. The Law of the Minimum states that biological growth is limited by the substance that is present in the minimum quantity with respect to the needs of the organism. Nitrogen and phosphorus are usually the nutrients that limit growth in most natural waters. If the limiting nutrient can be controlled, water quality improvements can be expected.

Depending on the species, algae require approximately 15 to 26 atoms of nitrogen for every atom of phosphorus. This ratio converts to 7 to 12 milligrams of nitrogen per 1 milligram of phosphorus on a mass basis. A ratio of total nitrogen to total phosphorus (TN:TP) of 15:1 is generally regarded as the dividing point between nitrogen and phosphorus limitation (U.S. EPA, 1980). Identification of the limiting nutrient becomes more certain as the total nitrogen to total phosphorus ratio moves farther away from the dividing point, with ratios of 10:1 or less providing a strong indication of nitrogen limitation and ratios of 20:1 or more strongly indicating phosphorus limitation (Porcella et al., 1974).

Table 3.3
Transparency, Total Suspended Solids, Chlorophyll a and Phytoplankton for Ten Lakes in LaGrange County

Lake	Transparency (meters)	Total Suspended Solids (mg/L)		Chlorophyll a (μg/L)	Phytoplankton (cells/L)	
		Surface	Bottom		0-5 ft tow	5 ft tow*
Adams	1.9	1.8	0.8	2.9	134,000	189,000
Atwood	2.1	0.7	0.9	3.0	31,000	35,000
Dallas	2.1	0.8	6.0	2.6	510,000	430,000
Hackenburg	2.3	0.4	1.6	3.8	792,000	642,000
Martin	4.2	0.8	1.6	3.5	511,000	132,000
Messick	2.2	0.4	1.8	3.3	667,000	132,000
Olin	3.5	1.5	0.2	1.2	49,000	29,000
Oliver	2.7	0.8	0.4	2.7	10,000	5,000
Westler	1.1	3.07	47.0	6.0	242,000	348,000
Witmer	1.1	6.1	6.0	6.7	960,000	1,025,000

Note:
* indicates 5 foot tow through the thermocline.

Table 3.4 Percentage of Blue-Green Algae			
Lake	**Percent**	**Lake**	**Percent**
Adams	99	Messick	82
Atwood	84	Olin	85
Dallas	94	Oliver	7
Hackenburg	84	Westler	97
Martin	91	Witmer	99

For all ten lakes, various forms of phosphorus and nitrogen were analyzed and are shown in Table 3.5. For most of the lakes, total phosphorus and orthophosphate concentrations were greater in the bottom waters than in the surface waters. High concentrations of phosphorus in the bottom waters are probably attributed to the gravitational settling of suspended solids (i.e. dead algal cells and soil particles) and the release of phosphorus from lake sediments under anoxic (low dissolved oxygen) conditions. For surface water samples, Hackenburg, Witmer Martin, and Messick Lakes recorded the highest total phosphorus concentrations, while Adams Lake recorded the lowest. Total phosphorus concentrations in the surface waters exceeding 0.02 mg/L is an indication of eutrophic conditions (EPA, 1980). For bottom water samples, Hackenburg, Messick, Westler and Witmer had the highest total phosphorus concentrations, and Olin and Oliver Lakes had the lowest.

Orthophosphorus concentrations in the surface waters were below the detectable limit, probably attributed to rapid algal uptake. For bottom waters, Hackenburg, Messick, Westler and Witmer Lakes had the highest orthophosphorus concentrations, and Atwood, Martin, Olin and Oliver Lakes recorded the lowest levels.

For all ten lakes, total Kjeldahl nitrogen concentrations in the bottom waters were greater than in the surface waters. High total Kjeldahl nitrogen concentrations in the bottom waters may be attributed to the settling of suspended solids and the buildup of ammonia nitrogen under low oxygen conditions. The highest total Kjeldahl nitrogen concentrations were reported in Hackenburg, Westler, and Messick Lakes. Surface total oxidized nitrogen (nitrate plus nitrite nitrogen) concentrations were higher in Olin, Martin, and Oliver Lakes. Bottom total oxidized nitrogen were highest in Olin, Martin, Oliver, and Dallas Lakes. In Olin and Oliver Lakes, high surface total oxidized nitrogen concentrations may be attributed to low algal uptake since these lakes had very low phytoplankton counts. With the fourth highest phytoplankton density, Martin Lake still recorded high total oxidized nitrogen concentrations. Martin Lake probably receives higher total oxidized nitrogen loadings than Olin & Oliver Lakes from surrounding farmland. Martin Lake is the first lake in the Martin-Olin-Oliver chain system. Based on the TN:TP ratio, phosphorus is the limiting nutrient for Martin Lake, therefore these higher inputs of nitrogen are simply not used. As for the high hypolimnetic total oxidized nitrogen concentrations, Olin, Martin, Oliver, and Dallas Lakes generally contain higher levels of dissolved oxygen throughout the water column. Under well-oxygenated (aerobic) conditions, nitrate and nitrite are more common than other nitrogen forms, such as ammonia and ammonium nitrogen.

For each of the lakes, the total nitrogen to total phosphorus ratio was calculated and the results are shown in Table 3.6. With the exception of Hackenburg Lake, phosphorus was the limiting nutrient for primary production during the August 1990 sampling period. Though the above ratio indicates that Hackenburg Lake was nitrogen limiting for this one study date, it is more than likely that the lake is phosphorus limiting. This is because the orthophosphorus concentration in the surface water sample was below the detection limit. Orthophosphorus is the only form of phosphorus that is directly available for algal growth. When orthophosphorus concentrations are below 0.01 mg/L, a lake is generally classified as phosphorus limiting system.

Table 3.5
Nutrient Concentrations for Ten Lake in LaGrange County

Lakes	Total Phosphorus (mg/L as P)		Orthophosphorus (mg/L as P)		Total Kjeldahl Nitrogen (mg/L as N)		Ammonia (mg/L as N)		Nitrate & Nitrite (mg/L as N)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Adams	<0.010	0.10	<0.01	0.052	0.60	1.13	n/a	n/a	<0.01	<0.01
Atwood	0.025	0.053	<0.01	<0.01	0.73	1.67	n/a	n/a	<0.01	<0.01
Dallas	0.017	0.087	<0.01	0.036	0.82	0.94	n/a	n/a	0.087	0.54
Hackenburg	0.170	0.760*	<0.01	0.860*	0.70	5.14	<0.1	3.38	0.075	<0.01
Martin	0.041	0.057	<0.01	<0.01	0.11	0.99	n/a	n/a	0.890	0.46
Messick	0.038	0.340*	<0.01	0.350*	0.72	2.64	<0.1	1.68	<0.01	<0.01
Olin	0.013	<0.010	<0.01	<0.01	0.66	0.71	n/a	n/a	0.960	0.92
Oliver	0.019	0.020	<0.01	<0.01	0.36	0.46	n/a	n/a	0.550	0.56
Westler	0.024	0.380	<0.01	0.240	0.50	3.92	n/a	n/a	<0.01	<0.01
Witmer	0.042	0.280	<0.01	0.220	0.88	1.87	n/a	n/a	<0.01	0.14

Note: (*) orthophosphorus concentrations should theoretical be less than or equal to total phosphorus concentrations. Error may have been introduced during sample collection, sample preparation and/or sample analysis

Table 3.6
Total Nitrogen to Total Phosphorus Ratio for Ten Lakes in LaGrange County

Lake	TN:TP	Lake	TN:TP
Adams	60	Messick	19
Atwood	29	Olin	125
Dallas	53	Oliver	48
Hackenburg	5	Westler	21
Martin	24	Witmer	21

3.4.5 Macrophytes

A macrophyte (aquatic plant) survey was conducted for each of the ten lakes. The survey consisted of macrophyte identification and delineation. Macrophytes are defined as aquatic plants ranging from completely submerged stands of algae to stands of rooted plants with floating leaves. Maps showing aquatic plant distribution are presented in Appendix E. The actual distribution was difficult to determine in many cases due to the widespread use of herbicides in the ten lakes. The following macrophytes were identified in the ten lakes:

arrow arum	*Peltandra*
coontail	*Ceratophyllum*
water lilies	*Nympheae, Nuphar*
bulrush	*Scirpus validus, S. americana, S. spp.*
pondweeds	*Potamogeton spp., P. amplifolius, P, crispus, P. robensii, P. natans*
milfoil	*Myriophyllum spp.*
cattails	*Typha*
swamp loosestrife	*Decodon*
pickerel weed	*Pontederia cordata*
purple loosestrife	*Lythrum salicaria*
waterweed	*Elodea canadensis*
bladderwort	*Utricularia*
buttonbush	*Cephalanthus occidentalis*
smartweed	*Polygonum*

There were at least two species of milfoil observed in the ten lakes. Since flowering parts and seed structures were not present, it was impossible to identify the species of this plant. However, one of the milfoil species was a robust species similar to *Myriophyllum heterophyllum* or *M. spicatum*. The other species was more diminutive species similar to *M. humile* or *M. farwellii*. If the robust species is one of the two mentioned above, attempts should be made to control the spreading of *M. spicatum* or *M. hererophyllum* since these species are invasive and may eventually out-compete native species. It was most prominent in Martin Lake, Oliver Lake, and Dallas Lake. Purple loosestrife, another invasive species, should be eliminated. Purple loosetrife was found near Oliver, Witmer, Atwood, and Dallas Lakes. No major infestations were observed.

3.4.6 Sediment Analyses

Sediment samples were collected from each lake on August 28, 1990. Each sample was analyzed for percent total solids, percent volatile solids, phosphorus, and nitrogen. Sediment sampling sites are shown in Figure 3.1. The percent volatile solids gives an indication of the organic fraction of the sediment. Total solids are the volatile solids plus the inorganic particles left after the volatiles have evaporated (percent volatile plus percent residual). Typically, lake sediments are about fifty to seventy percent water. Information on the solids and nutrient content of sediments in the LaGrange County lakes is summarized in Table 3.7. Sediment data from Olin Lake is unavailable due to sample container damage in the mail. Sediment samples were also analyzed for particle size, and these results are presented in Table 3.8. All sediment data for the ten lakes is included in Appendix F.

Table 3.7
Concentrations of Solids and Nutrients in the Sediments of Ten LaGrange County Lakes

Lake	Total Solids (percent)	Volatile Solids (percent)	Total Phosphorus (mg/kg)	Total Nitrogen (mg/kg)
Adams	41.77	9.14	147	23.0
Atwood	32.82	17.15	390	22.7
Dallas	35.25	10.72	7.05	1538
Hackenburg	43.03	31.71	2.21	3.1
Martin	52.15	15.52	1569	13.7
Messick	34.55	23.01	35.2	87.0
Olin	N/A	N/A	N/A	N/A
Oliver (East)	77.6	1.2	12.3	10.9
Oliver (West)	47.98	14.69	301	2090
Westler	29.48	12.44	306	803
Witmer	43.87	22.19	489	12.0

Table 3.8
Particle Size Distribution Within the Sediments of Ten LaGrange County Lakes

Lake	Fine Sand (percent)	Silt (percent)	Clay (percent)	Colloids (percent)
Adams	12.8	87.2	< 1.0	< 1.0
Atwood	17.6	82.4	< 1.0	< 1.0
Dallas	8.2	91.8	< 1.0	< 1.0
Hackenburg	5.8	94.2	< 1.0	< 1.0
Martin	9.7	90.3	< 1.0	< 1.0
Messick	8.3	91.7	< 1.0	< 1.0
Olin	N/A	N/A	N/A	N/A
Oliver (East)	77.9	22.1	< 1.0	< 1.0
Oliver (West)	17.9	82.1	< 1.0	< 1.0
Westler	6.3	93.7	< 1.0	< 1.0
Witmer	16.9	68.2	14.9	< 1.0

Phosphorus in sediments of the ten lakes probably exists in three major forms: calcium phosphate precipitate, adsorbed onto sediment particles, and as organic detritus (decomposing organic matter). Phosphorus content was high in sediments from Atwood, Oliver (west), Westler, and Witmer Lakes, and very high in Martin Lake as shown in Table 3.7. In Atwood, Westler, and Witmer Lakes, phosphorus was primarily in detrital form. In the Oliver (west) and Martin Lake samples, phosphorus appears to be in both organic and inorganic forms.

Nitrogen in lake sediments is most likely to be associated with detritus. Nitrogen concentrations were high in sediments from Westler Lake, and very high in Oliver (west) and Dallas Lake sediments as shown in Table 3.7.

When the lakes stratify in the summer, pH decreases in the bottom waters, creating a suitable chemical environment for phosphorus and nitrogen to dissolve from the sediments and mix throughout the bottom waters. When the water column mixes, these nutrients become available to algae growing in the surface waters and an algal bloom can result. The release of nutrients from lake sediments is called internal nutrient loading. Since phosphorus is the limiting nutrient in most of the study lakes, internal phosphorus loading is of primary concern. The results of sediment analysis indicate that Adams, Atwood, Martin, Oliver (west), Westler, and Witmer Lakes may receive significant internal phosphorus loads.

Based on guidelines published by IDEM, the maximum background concentration for total phosphorus and total Kjeldahl nitrogen are 610 and 1,500 mg/Kg. Only the sediment sample from Martin Lake exceeds the maximum background concentration for phosphorus. This sediment sample is below the "low concern" level for phosphorus. The "low concern" level is defined as 2 to 10 times greater than the maximum background concentration. Under IDEM's guidelines, maximum background concentrations are only given for total Kjeldahl nitrogen and not for total nitrogen. As shown in Table 3.7, sediment samples were only analyzed for total nitrogen. Assuming the worse case scenario (total nitrogen is only composed of total Kjeldahl nitrogen), the sediment samples from Dallas Lake and the west end of Oliver Lake would exceed the maximum background concentration for total Kjeldahl nitrogen. In any event, these sediment samples are still below the "low concern" level for total Kjeldahl nitrogen.

As shown in Table 3.8, most lake sediments are composed of silt. Nine of the eleven sediment samples contained silt fractions greater than 82 percent. In the Oliver (East) and Witmer sediment samples, sand fractions were greater than silt fractions. The Oliver (East) and Witmer sediment samples contained 77.9 and 16.9 percent sand, respectively.

3.5 Lake Trophic State

The trophic status for the ten lakes were determined using the Indiana Department of Environmental Management Eutrophic Index, Carlson's Trophic State Index and criterion set forth by the United States Environmental Protection Agency.

3.5.1 IDEM Trophic Index

Based on the criterion as set forth by the Indiana Department of Environmental Management (IDEM), the trophic status of the ten lakes in LaGrange County were determined using their Eutrophic Index. The index, which is a trophic continuum ranging from 0 to 75, assigns eutrophy points for a variety of parameters.

The sum of eutrophy points for these parameters is the IDEM Eutrophic Index for a given lake. According the IDEM, lakes are classified as listed below.

Class I - highest quality, least eutrophic lakes (0 - 25 points)
Class II - intermediate quality, intermediate eutrophic lakes (26 - 50 points)
Class III - lowest quality, advanced eutrophic lakes (51 - 75 points)
Class IV - remnant natural lakes and oxbow lakes

As shown in Table 3.9, IDEM Eutrophic Index values ranged from 8 to 56 for the ten lakes. Only Hackenburg and Messick Lakes were analyzed for ammonia nitrogen, therefore ammonia nitrogen and organic nitrogen (total Kjeldahl nitrogen minus ammonia) were included directly in Eutrophic Index determination. Due to the sample volume loss during transportation, the remaining eight lakes were not analyzed for ammonia nitrogen. For these lakes, a range of eutrophic points for ammonia and organic nitrogen were determined by assuming the following three case scenarios: (1) the organic nitrogen concentration was equal to the total Kjeldahl nitrogen concentration, (2) the ammonia nitrogen concentration is equal to the total Kjeldahl nitrogen concentration, and (3) both ammonia and organic nitrogen are equal to one-half the total Kjeldahl nitrogen concentration.

Table 3.9
IDEM Eutrophic Index for Ten Lakes in LaGrange County, Indiana

Parameter	Adams	Atwood	Dallas	Hackenburg	Martin
Total Phosphorus	2	2	2	4	2
Soluble Phosphorus	1	0	0	4	0
Organic Nitrogen	0-3	0-3	0-3	3	0-2
Nitrate Nitrogen	0	0	1	0	2
Ammonia Nitrogen	0-3	0-4	0-3	4	0-3
% Dissolved Oxygen Saturation	0	0	0	0	0
% Water Column Containing Dissolved Oxygen	0	0	0	0	0
Light Penetration	0	0	0	0	0
% Light Transmission	4	0	4	4	4
Total Plankton (0-5 ft tow)	10	4	10	10	10
Blue-green Dominance	5	5	5	5	5
Total Plankton (5 ft tow**)	4	2	10	10	10
Blue-green Dominance	5	5	5	5	5
Population over 950,000	0	0	0	0	0
IDEM Eutrophic Index	33-34*	24-26*	39-40*	49	34-35*
IDEM Eutrophic Index†	36	16	34	56	32

Note:
* estimated IDEM trophic values, refer to section 3.4.1.
** indicates 5 ft tow through the thermocline.
† source: Indiana Department of Environmental Management, 1992.

Table 3.9 (Continued)
IDEM Eutrophic Index for Ten Lakes in LaGrange County, Indiana

Parameter	Messick	Olin	Oliver	Westler	Witmer
Total Phosphorus	3	0	0	4	3
Soluble Phosphorus	3	0	0	3	3
Organic Nitrogen	2	0-2	0	0-4	0-3
Nitrate Nitrogen	0	3	2	0	0
Ammonia Nitrogen	2	0-3	0-2	0-4	0-4
% Dissolved Oxygen Saturation	0	0	0	2	2
% Water Column Containing Dissolved Oxygen	0	0	0	0	0
Light Penetration	0	0	0	6	6
% Light Transmission	4	4	4	4	4
Total Plankton (0-5 ft tow)	10	4	2	10	10
Blue-green Dominance	5	5	0	5	5
Total Plankton (5 ft tow**)	4	2	0	10	10
Blue-green Dominance	5	5	0	5	5
Population over 950,000	0	0	0	0	5
IDEM Eutrophic Index	39	24-26*	8-10*	53-56*	56-58*
IDEM Eutrophic Index†	30	22	20	52	33

Based on the Eutrophic Index values reported in Table 3.9, only Oliver Lake was classified as a Class I system. Both Atwood Lake and Olin Lake were considered Class I/Class II lakes. Adams, Dallas, Hackenburg, Martin, and Messick Lakes were categorized as Class II systems, while Westler and Witmer Lakes were ranked as Class III lakes.

In Table 3.9, Eutrophic Index values were determined by the Indiana Department of Environmental Management for the ten LaGrange County lakes (IDEM, 1992). These values were based on data collected from 1988 through 1990. In comparing these values to the values determined as part of this study, seven of the ten Eutrophic Index values reported in this study are greater than those reported by IDEM.

3.5.2 Carlson's Trophic State Index

In addition to the IDEM Eutrophic Index, trophic status was determined by using the Carlson's Trophic State Index. The Carlson's Trophic State Index is a trophic continuum ranging from 0 to 100. Trophic State Index values greater than 50 are generally indicative of eutrophic lake conditions, while values less than 35 are indicative of oligotrophic lake conditions. Trophic State Index values may be calculated for chlorophyll a concentrations, total phosphorus concentrations and secchi disk transparency. For the ten lakes, Trophic State Index values were based on one summer value for each parameter.

As shown in Table 3.10, Trophic State Index values were the highest for Witmer, Westler, Messick and Hackenburg Lakes and the lowest for Olin. Hackenburg Lake, Witmer Lake and Westler Lake are classified as eutrophic. Messick Lake is classified as highly mesotrophic or slightly eutrophic. The remaining and the remaining six lakes are classified as mesotrophic.

3.5.3 EPA Trophic Criteria

The United States Environmental Protection Agency (EPA) has set ranges for chlorophyll a concentrations and Secchi disk transparency as indicators of lake trophic status. Based on the EPA criterion, a lake system may be classified as eutrophic if chlorophyll a levels are greater than or equal to 6 to 10 μg/L and transparencies are less than or equal to 1.5 to 2 meters (4.9 to 6.6 feet). A lake system may be classified as oligotrophic if chlorophyll a levels are less than or equal to 2 to 4 μg/L nd transparencies are greater than or equal to 3 to 5 meters (9.8 to 16.4 feet).

Based on the above criterion, Witmer and Westler Lakes were classified as eutrophic systems while Olin Lake was classified as oligotrophic. The data for the remaining lakes indicate that these systems were mesotrophic.

Table 3.10 Carlson's Trophic Indices for Ten Lakes in LaGrange County, Indiana				
Lake	**Total Phosphorus**	**Chlorophyll a**	**Transparency**	**Average TSI**
Adams	30.5	41.0	50.7	40.7
Atwood	50.6	41.3	49.3	47.1
Dallas	45.0	39.9	49.3	44.7
Hackenburg	78.2	43.7	48.0	56.6
Martin	57.7	42.9	39.3	46.6
Messick	56.6	42.3	48.6	49.2
Olin	41.2	32.4	41.9	38.5
Oliver	46.6	40.3	45.7	44.2
Westler	50.0	48.1	58.6	52.2
Witmer	58.1	49.2	58.6	55.3

3.6 Stream Water Quality Data

Inflowing tributaries and lake outlets were sampled during base flow (low flow) and storm flow (high flow) conditions on August 14, 1990, and May 31, 1991, respectively. These stream sampling sites are shown in Figure 3.1. On August 14, 1990, samples were analyzed for total phosphorus, orthophosphorus, nitrate plus nitrite, ammonia, total Kjeldahl nitrogen, pH, alkalinity, conductivity, fecal coliform and fecal streptococcus. On May 31, 1991, samples were analyzed for total phosphorus, orthophosphorus, nitrate plus nitrite, ammonia, total Kjeldahl nitrogen, fecal coliform and fecal streptococcus. All stream water quality data is included in Appendix D.

It is important to remember that the stream samples represent a single "snapshot" of water quality in the stream at a particular time. Concentrations of water quality parameters in streams can fluctuate widely, depending on runoff and flow conditions, as well as land management activities upstream.

For the ten LaGrange County lakes, stream water quality under both base flow and storm flow conditions is discussed in the following paragraphs. For a brief discussion of total phosphorus, orthophosphorus, nitrate plus nitrite, ammonia, total Kjeldahl nitrogen, pH, alkalinity, and conductivity, refer to Section 3.3, Water Quality Data.

In addition to the above water quality parameters, water samples were analyzed for fecal coliform and fecal streptococcus. Both fecal coliform (FC) and fecal streptococcus are groups of bacteria, which are indicators of fecal pollution from both human and other animal sources. Indicator groups of bacteria reflect the potential presence of pathogenic organisms (Thomann and Mueller, 1987). As the number of the above bacteria increase, the chance of encountering a pathogenic organism also increases. In general, testing procedures for "...pathogenic bacteria are difficult to perform and generally are not reproducible" (Hammer, 1986). Therefore, test procedures for nonpathogenic indicator bacteria is more desirable than for specific pathogenic organisms.

In attempting to identify the significance of bacterial pollution within the watershed, the fecal coliform to fecal streptococcus ratio (FC/FS) was calculated for all stream samples. The fecal coliform to fecal streptococcus ratio is commonly used as an indicator of the source of bacterial contamination in streams. A FC/FS ratio less than 0.7 is generally assumed to indicate that non-human sources are the primary cause of the observed pollution, while a FC/FS ratio greater than 4.1 generally is assumed to result from human wastes. A FC/FS ratio between 0.7 to 4.1 suggests a combination of human and animal sources. Care must be exercised when interpreting FC/FS ratios because a number of factors, such as stream temperature and pH, and travel time from the pollutant source, may lead to erroneous conclusions (APHA, 1985).

The FC/FS ratio is only intended as an indication of the bacteriological water quality at a particular stream location at the time of sampling, and is not intended to identify individual sources of pollution. This is primarily due to the fact that fecal coliform and fecal streptococcus differ in decay rates, hence the FC/FS ratios will evidently change as the distance from the pollution source becomes greater.

Base Flow Conditions

In order to assess the water quality of streams within the ten Indiana lakes' watershed, seven lake outlets and fifteen lake tributaries were sampled on August 14, 1990. Samples were analyzed for total phosphorus, orthophosphorus, nitrate plus nitrite, ammonia, total Kjeldahl nitrogen, pH, alkalinity, conductivity, fecal coliform and fecal streptococcus. Stream water quality data for August 14, 1990, is presented in Tables 3.11 through 3.13.

In Table 3.11, pH, alkalinity, conductivity and total suspended solid concentration are shown for twenty-two streams. For these streams, the pH ranged from 7.3 to 8.3 standard units with mean value of 8.0. The inlet to Messick Lake (at the junction of Route 550 South) recorded the lowest pH value, and the inlet to Adams Lake and the outlet of Dallas Lake recorded the highest values. For most surface waters, pH values typically fall within a range of 6 to 9 standard units. Alkalinity ranged from 116 to 302 mg/L as calcium carbonate with a mean concentration of 205 mg/L. The outlet of Atwood Lake recorded the lowest alkalinity concentrations and the Dove Creek inlet, which feeds onto Oliver Lake, and the north east inlet to Witmer Lake recorded the highest concentrations.

Conductivity ranged from 251 to 679 micromhos with a mean value of 483 micromhos. The lowest and highest conductivity values were recorded at the outlet of Atwood Lake and the north east inlet of Witmer Lake, respectively. For both surface water and groundwater, conductivity values typically range from 50 to 1500 micromhos. For these streams, total suspended concentrations ranged from 0.4 to 29 mg/L with a mean value of 8.37 mg/L. The outlets of Dallas and Witmer Lakes recorded the lowest total suspended solid concentrations, while the south east inlet into Witmer Lake recorded the highest value.

In Table 3.12, nitrate plus nitrite, ammonia, total Kjeldahl nitrogen, total phosphorus and orthophosphorus are shown for twenty-two streams in the ten LaGrange County lakes watershed. Nitrate plus nitrate concentrations ranged from 0.029 to 2.090 mg/L as nitrogen with a mean concentrations of 0.71 mg/L. The lowest and highest nitrate plus nitrite nitrogen concentrations were recorded in the inlets of Adams Lake and Messick Lake (at the junction of Route 550 South). Ammonia nitrogen levels ranged from below the detection limit to 0.039 mg/L as nitrogen with a mean concentration of 0.10 mg/L. Of the twenty-two streams analyzed, fifteen streams recorded values at or below the detection limit. The highest ammonia nitrogen concentration was recorded in the inlet to Hackenburg Lake (at the junction of Route 75 West). Total Kjeldahl nitrogen concentrations ranged from 0.051 to 1.46 mg/L as nitrogen with a mean level of 0.55 mg/L. The lowest and highest total Kjeldahl nitrogen concentrations were at the inlet of Olin Lake and the inlet of Messick Lake (at the junction of Route 550 South).

For the twenty-two streams that were sampled, total phosphorus concentrations ranged from below the detection limit of 0.01 to 0.64 mg/L as phosphorus. For these streams, the mean total phosphorus concentration was 0.14 mg/L as phosphorus. The lowest and highest total phosphorus levels were reported at the outlet of Westler Lake and the inlet of Messick Lake (at the junction of Route 550 South). Orthophosphorus concentrations ranged from less than 0.01 to 0.18 mg/L as phosphorus. The mean orthophosphorus concentration was 0.02 mg/L as phosphorus and the highest orthophosphorus concentration was recorded at the inlet of Messick Lake (at the junction of Route 550 South).

Both fecal coliform and fecal streptococcus counts are shown in Table 3.13 for twenty-two streams within the ten LaGrange County lakes' watershed. Fecal coliform counts ranged from 2 to 370,000 cells/100 mL with a mean value of 69,260 cells/100 mL. Of all the streams, the inlet of Oliver and the north east inlet of Witmer recorded the lowest and highest counts, respectively. Recently, the Indiana Department of Environmental Management (IDEM) have switch their water quality standard for bacterial contamination from fecal coliform to *Escherichia coli*. Of the streams listed in Table 3.13, twelve exceeded the old IDEM standard of 400 fecal coliform bacteria per 100 mL per water sample for full body contact. As for fecal streptococcus, counts ranged from less than 1 to 100 cells/100 mL with a mean value of 20 cells/100 mL. The highest fecal streptococcus count was recorded at the south east inlet of Martin Lake.

For the above streams, no fecal coliform to fecal streptococcus (FC/FS) ratios were calculated due to low fecal streptococcus counts. The use of FC/FS ratios is considered not meaningful when fecal streptococcus counts are less or equal to 100 cells/100 mL. The fecal streptococcus species, S. faecalis subsp. liquefaciens, is generally dominant at these low levels, and this species is associated with vegetation, insects, and soils, rather than with animals.

Storm Flow Conditions

In order to assess the water quality of streams within the ten Indiana lakes' watershed during a storm event, seven lake outlets and fifteen lake tributaries were sampled on May 31, 1991. On May 30 and May 31, 1991, Kendallville, Indiana received 2.90 and 1.60 inches of rainfall (National Climate Data Center, personal communication). Kendallville is approximately 9 miles south east of Adams Lake. Stream samples were analyzed for total phosphorus, orthophosphorus, nitrate plus nitrite, ammonia, total Kjeldahl nitrogen, fecal coliform and fecal streptococcus. Stream flow water quality data for May 31, 1991, is presented in Tables 3.14 through 3.15.

In Table 3.15, nitrate plus nitrite, ammonia, total Kjeldahl nitrogen, total phosphorus and orthophosphorus are shown for twenty-two streams in the ten lakes watershed. Nitrate plus nitrate concentrations ranged from 0.05 to 10.88 mg/L as nitrogen with a mean concentrations of 3.39 mg/L. The lowest and highest nitrate plus nitrite nitrogen concentrations were measured in the outlet of Atwood Lake and the inlet of Adams Lake, respectively. Ammonia nitrogen levels ranged from below the detection limit of 0.1 to 0.57 mg/L as nitrogen with a mean concentration of 0.22 mg/L. Of the twenty-two streams analyzed, four streams recorded values at or below the detection limit. The highest ammonia nitrogen concentration was recorded in the inlets to Messick Lake (at the junction of Route 550 South) and Westler Lake (at the junction of Route 125 East). Total Kjeldahl nitrogen concentrations ranged from 0.05 to 10.18 mg/L as nitrogen with a mean level of 1.53 mg/L. The lowest and highest total Kjeldahl nitrogen concentrations were at the inlet of Oliver Lake and the inlet of Messick Lake (at the junction of Route 550 South), respectively.

For the twenty-two streams that were sampled, total phosphorus concentrations ranged from 0.017 to 1.663 mg/L as phosphorus. For these streams, the mean total phosphorus concentration was 0.20 mg/L as phosphorus. The lowest and highest total phosphorus levels were reported at the inlets of Oliver Lake and Messick Lake (at the junction of Route 550 South). Orthophosphorus concentrations ranged from 0.002 to 0.394 mg/L as phosphorus. The mean orthophosphorus concentration was 0.063 mg/L as phosphorus. The lowest orthophosphorus concentration was measured in the outlet of Witmer Lake, while the highest level was recorded at the inlet of Messick Lake (at the junction of Route 550 South).

Both fecal coliform and fecal streptococcus counts are shown in Table 3.15 for twenty-two streams within the ten LaGrange County lakes' watershed. Fecal coliform counts ranged from 80 to 330,000 cells/100 mL with a mean value of 33,585 cells/100 mL. Of all the streams, the outlet of Witmer Lake and the inlet of Messick Lake (at the junction of Route 550 South) recorded the lowest and highest counts, respectively. Recently, the Indiana Department of Environmental Management (IDEM) have switch their water quality standard for bacterial contamination from fecal coliform to *Escherichia coli*. Of the streams listed in Table 3.13, nineteen exceeded the old IDEM standard of 400 fecal coliform bacteria per 100 mL per water sample for full body contact. As for fecal streptococcus, counts ranged from 90 to 190,000 cells/100 mL with a mean value of 32,142 cells/100 mL. The highest and lowest fecal streptococcus counts were measured at the inlet of Oliver Lake and the inlet of Messick Lake (at the junction of Route 550 South), respectively.

For twenty of the twenty-two streams, fecal coliform to fecal streptococcus (FC/FS) ratios were calculated. The use of FC/FS ratios is considered not meaningful when fecal streptococcus counts are less or equal to 100 cells/100 mL. The fecal streptococcus species, S. faecalis subsp. liquefaciens, is generally dominant at these low levels, and this species is associated with vegetation, insects, and soils, rather than with animals. Therefore due to low fecal streptococcus cell counts, no FC/FS ratios were determined for the outlet of Dallas Lake and the inlet to Oliver Lake.

For these twenty streams, calculated FC/FS ratios were as follows: two above 4.1, five between 0.7 and 4.1, and thirteen below 0.7. The outlet of Oliver Lake and the inlet of Witmer Lake (near the town of Wolcottville) recorded FC/FS ratios exceeding 4.1. FC/FS ratios greater than 4.1 suggest that the pollution is associated with domestic waste. At the inlets to Martin Lake (south east), Hackenburg Lake (at the junction of Route 75 West), Messick Lake (at the junction at Route 550 South), Westler Lake (at the junction of Route 125 East), Witmer Lake (south east), FC/FS ratios fell between 0.7 and 4.1. FC/FS ratios between 0.7 and 4.1 are indicative of pollution from both domestic and animal wastes. The remaining inlets and outlets obtained FC/FS ratios below 0.7. For these thirteen streams, FC/FS ratios below 0.7 suggest that pollution is primarily attributed to animal wastes.

For the above FC/FS ratios, it is important to remember each ratio only provides a comparison between fecal coliform and fecal streptococcus populations at each of the sampling stations. If a source of pollution is a considerable distance upstream, the FC/FS ratio may lead to erroneous conclusions since fecal streptococcus decay rates generally exceed those for fecal coliforms. For more conclusive results, water samples should be collected in close proximity of a suspect site, thereby reducing the bacterial decay rate effects. Another option is to analyze fecal coliform and streptococcus data via mathematical models (Thomann and Mueller, 1987). By modeling fecal coliform and fecal streptococcus counts, decay rates (die-off rates) of both groups of bacteria are addressed.

Table 3.11
Stream Water Quality During Base Flow Condition

Lake	Sample Location	pH (S.U.)	Alkalinity (mg/L as $CaCO_3$)	Conductivity (micromhos/cm)	Total Suspended Solids (mg/L)
Adams	Inlet	8.3	134	349	8.0
	Outlet (to Witmer Lake)	7.9	128	341	8.5
Atwood	Outlet (to Witmer Lake)	7.7	116	251	4.6
Dallas	Outlet (to Hackenburg Lake)	8.3	170	417	0.4
Hackenburg	Inlet at Route 75 W	7.4	294	669	0.9
	Inlet at Route 550 S	7.8	156	393	7.2
Martin	Inlet (South East)	8.0	276	609	5.4
	Inlet (North East)	8.2	230	544	1.4
Messick	Inlet (from Hackenburg Lake)	7.9	162	408	6.2
	Inlet at Route 550 S	7.3	232	521	4.2
	Outlet	8.2	166	404	8.6
Olin	Inlet (from Martin Lake)	8.2	234	531	4.7

Table 3.11 (Continued)
Stream Water Quality During Base Flow Condition

Lake	Sample Location	pH (S.U.)	Alkalinity (mg/L as $CaCO_3$)	Conductivity (micromhos/cm)	Total Suspended Solids (mg/L)
Oliver	Inlet (from Olin Lake)	8.2	180	443	4.4
	Dove Creek	7.8	302	672	12
	Inlet East	8.0	278	643	16
	Outlet (to Hackenburg Lake)	8.1	158	402	6.3
Westler	Inlet at Route 125 E	7.8	272	623	16
	Outlet (to Dallas Lake)	8.1	178	412	4
Witmer	Inlet (South East)	7.9	192	457	29
	Inlet at Wolcottville	7.9	180	442	23
	Inlet (North East)	7.8	302	679	13
	Outlet (to Westler Lake)	8.2	176	415	0.4

Table 3.12
Stream Water Quality During Base Flow Condition

Lake	Sample Location	Nitrate + Nitrate (mg/L)	Ammonia (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	Orthophosphate (mg/L)
Adams	Inlet	0.029	0.18	1.13	0.03	<0.01
	Outlet (to Witmer Lake)	0.082	0.13	0.39	0.16	<0.01
Atwood	Outlet (to Witmer Lake)	0.860	<0.10	0.54	0.026	<0.01
Dallas	Outlet (to Hackenburg Lake)	0.110	<0.10	0.35	0.19	<0.01
Hackenburg	Inlet at Route 75 W	0.670	0.39	1.26	0.31	0.10
	Inlet at Route 550 S	1.000	<0.10	0.26	0.073	<0.01
Martin	Inlet (South East)	0.900	0.13	0.30	0.058	<0.01
	Inlet (North East)	0.830	<0.10	0.53	0.084	<0.01
Messick	Inlet (from Hackenburg Lake)	0.980	<0.10	0.30	0.17	<0.01
	Inlet at Route 550 S	2.090	0.35	1.46	0.64	0.18
	Outlet	0.600	<0.10	0.38	0.27	<0.01
Olin	Inlet (from Martin Lake)	0.300	<0.10	0.051	0.14	<0.01

Table 3.12 (Continued) Stream Water Quality During Base Flow Condition						
Lake	Sample Location	Nitrate + Nitrate (mg/L)	Ammonia (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	Orthophosphate (mg/L)
Oliver	Inlet (from Olin Lake)	0.66	<0.1	0.49	0.031	<0.01
	Dove Creek	1.13	0.12	0.64	0.200	0.029
	Inlet East	0.58	<0.1	0.33	0.210	<0.01
	Outlet (to Hackenburg Lake)	0.058	<0.1	0.26	0.120	<0.01
Westler	Inlet at Route 125 E	0.97	<0.1	0.45	0.110	<0.01
	Outlet (to Dallas Lake)	1.25	<0.1	0.60	<0.01	<0.01
Witmer	Inlet (South East)	0.98	0.12	0.60	0.16	0.024
	Inlet at Wolcottville	0.28	<0.1	0.69	0.08	<0.01
	Inlet (North East)	1.14	<0.1	0.90	0.052	<0.01
	Outlet (to Westler Lake)	0.047	<0.1	0.17	0.014	<0.01

Table 3.13
Stream Water Quality During Base Flow Condition

Lake	Sample Location	Fecal Coliform (FC) (cells/100 mL)	Fecal Streptococcus (FS) (cells/100 mL)	FC/FS Ratio*
Adams	Inlet	190,000	10	Not Applicable
	Outlet (to Witmer Lake)	82	20	Not Applicable
Atwood	Outlet (to Witmer Lake)	39	50	Not Applicable
Dallas	Outlet (to Hackenburg Lake)	27	<1	Not Applicable
Hackenburg	Inlet at Route 75 W	250	<1	Not Applicable
	Inlet at Route 550 S	9,000	10	Not Applicable
Martin	Inlet (South East)	128,000	100	Not Applicable
	Inlet (North East)	297,000	50	Not Applicable
Messick	Inlet (from Hackenburg Lake)	18	10	Not Applicable
	Inlet at Route 550 S	197,000	10	Not Applicable
	Outlet	15	30	Not Applicable
Olin	Inlet (from Martin Lake)	760	10	Not Applicable

* Fecal coliform to fecal streptococcus ratio is not valid when the fecal streptococcus counts are less than 100 per 100/mL

Table 3.13 (Continued) Stream Water Quality During Base Flow Condition				
Lake	**Sample Location**	**Fecal Coliform (FC) (cells/100 mL)**	**Fecal Streptococcus (FS) (cells/100 mL)**	**FC/FS Ratio***
Oliver	Inlet (from Olin Lake)	2	20	Not Applicable
	Dove Creek	18,000	<1	Not Applicable
	Inlet East	2,300	<1	Not Applicable
	Outlet (to Hackenburg Lake)	12	10	Not Applicable
Westler	Inlet at Route 125 E	9,100	10	Not Applicable
	Outlet (to Dallas Lake)	9	<1	Not Applicable
Witmer	Inlet (South East)	270,000	30	Not Applicable
	Inlet at Wolcottville	32,000	<1	Not Applicable
	Inlet (North East)	370,000	<1	Not Applicable
	Outlet (to Westler Lake)	110	70	Not Applicable

* Fecal coliform to fecal streptococcus ratio is not valid when the fecal streptococcus counts are less than 100 per 100/mL

Table 3.14
Stream Water Quality During Storm Flow Condition

Lake	Sample Location	Nitrate + Nitrate (mg/L)	Ammonia (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	Orthophosphate (mg/L)
Adams	Inlet	10.88	0.49	2.53	0.352	0.107
	Outlet (to Witmer Lake)	0.30	0.11	0.66	0.039	0.029
Atwood	Outlet (to Witmer Lake)	0.05	<0.1	0.73	0.049	0.029
Dallas	Outlet (to Hackenburg Lake)	0.23	<0.1	0.49	0.023	0.005
Hackenburg	Inlet at Route 75 W	6.82	0.47	2.35	0.441	0.279
	Inlet at Route 550 S	1.12	<0.1	0.54	0.039	0.027
Martin	Inlet (South East)	0.48	0.17	0.78	0.040	0.003
	Inlet (North East)	3.07	0.16	1.70	0.155	0.033
Messick	Inlet (from Hackenburg Lake)	0.48	0.13	0.60	0.042	0.008
	Inlet at Route 550 S	7.12	0.57	10.18	1.663	0.394
	Outlet	0.36	0.22	1.28	0.099	0.026
Olin	Inlet (from Martin Lake)	1.77	0.14	0.72	0.071	0.008

Table 3.14 (Continued)
Stream Water Quality During Storm Flow Condition

Lake	Sample Location	Nitrate + Nitrate (mg/L)	Ammonia (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	Orthophosphate (mg/L)
Oliver	Inlet (from Olin Lake)	1.96	0.13	0.50	0.017	0.033
	Dove Creek	7.76	0.26	2.23	0.220	0.058
	Inlet East	1.81	0.16	0.85	0.183	0.083
	Outlet (to Hackenburg Lake)	1.78	<0.1	0.47	0.044	0.025
Westler	Inlet at Route 125 E	8.40	0.57	1.44	0.238	0.094
	Outlet (to Dallas Lake)	1.40	0.12	0.94	0.031	0.005
Witmer	Inlet (South East)	4.47	0.31	1.45	0.253	0.092
	Inlet at Wolcottville	5.75	0.21	1.27	0.163	0.021
	Inlet (North East)	8.10	0.14	1.33	0.111	0.021
	Outlet (to Westler Lake)	0.53	0.32	0.62	0.025	0.002

Table 3.15
Stream Water Quality During Storm Flow Condition

Lake	Sample Location	Fecal Coliform (FC) (cells/100 mL)	Fecal Streptococcus (FS) (cells/100 mL)	FC/FS Ratio*
Adams	Inlet	40,000	150,000	0.27
	Outlet (to Witmer Lake)	690	3,500	0.20
Atwood	Outlet (to Witmer Lake)	120	3,400	0.04
Dallas	Outlet (to Hackenburg Lake)	690	40	Not Applicable
Hackenburg	Inlet at Route 75 W	60,000	22,000	2.73
	Inlet at Route 550 S	1,700	5,000	0.34
Martin	Inlet (South East)	4,000	2,800	1.43
	Inlet (North East)	16,000	70,000	0.23
Messick	Inlet (from Hackenburg Lake)	510	2,100	0.24
	Inlet at Route 550 S	330,000	190,000	1.74
	Outlet	4,100	5,900	0.69
Olin	Inlet (from Martin Lake)	5,900	10,000	0.59

* Fecal coliform to fecal streptococcus ratio is not valid when the fecal streptococcus counts are less than 100 per 100/mL

Table 3.15 (Continued) Stream Water Quality During Storm Flow Condition				
Lake	**Sample Location**	**Fecal Coliform (FC) (cells/100 mL)**	**Fecal Streptococcus (FS) (cells/100 mL)**	**FC/FS Ratio***
Oliver	Inlet (from Olin Lake)	90	90	Not Applicable
	Dove Creek	50,000	130,000	0.38
	Inlet East	1,800	10,000	0.18
	Outlet (to Hackenburg Lake)	13,000	2,000	6.5
Westler	Inlet at Route 125 E	13,000	16,000	0.81
	Outlet (to Dallas Lake)	3,300	21,000	0.16
Witmer	Inlet (South East)	70,000	40,000	1.75
	Inlet at Wolcottville	120,000	12,000	10.0
	Inlet (North East)	3,900	11,000	0.35
	Outlet (to Westler Lake)	80	290	0.28

* Fecal coliform to fecal streptococcus ratio is not valid when the fecal streptococcus counts are less than 100 per 100/mL

4.0 Pollutant Sources

Pollutants can enter a lake from both point and nonpoint sources. Point sources are defined as all wastewater effluent discharges within a watershed. All point source dischargers of municipal and industrial waste are required to operate under a permit and are assigned a specific discharge number by the National Pollutant Discharge Elimination System (NPDES). The permit requirements determine the amounts of specified pollutants which can be present in the waste effluent for each discharger and also contain monitoring requirements to ensure that discharge limitations are observed. Point sources can include industrial, municipal, and domestic discharges.

All other pollutant sources within a watershed are classified as nonpoint sources. Nonpoint sources can contribute pollutants to a lake through inflow from tributaries, direct runoff, direct precipitation on the lake surface, or through internal loading and groundwater inputs. Both natural events, such as precipitation and runoff, and human activities, including agriculture, silviculture, and construction, can contribute pollutants from nonpoint sources. Nonpoint sources can be difficult to quantify but are important because they often constitute the major source of pollutants to a lake.

Calculations of pollutant loads require information on the water quality of influent streams, lake and watershed interactions, and stream flow. Pollutant loading determination may also require data analysis, modeling, and engineering assumptions. Many sources of error can be incorporated into the results because of the number of water quality samples which must be analyzed, the data analysis required, and the number of assumptions which must be made.

Errors resulting from the water quality analyses can be minimized through a good laboratory quality assurance/quality control program, but the other errors involved can only be reduced through the collection of large amounts of chemical and hydrologic data from the entire watershed. This approach was beyond the scope of the ten lakes study. As a result, the pollutant loads presented in this report should be considered as best estimates rather than absolute values of the actual pollutant loads.

4.1 Hydrologic Budget

No direct flow measurements were made on any of the lake inlets or at the lake outlet during this study; however, estimates can be made by using data from United State Geological Survey (USGS) monitoring stations on similar watersheds nearby. There are three USGS monitoring stations that are close enough to the study watersheds in size and location to be used for these estimates (USGS, 1988). Average estimated discharges for each drainage basin were calculated by multiplying the average annual discharge per square mile at the USGS monitoring gages by the area of the watershed of interest. Table 4.1 presents the pertinent data from the three USGS stations used to estimate annual discharge of the LaGrange watersheds.

Table 4.1 Data from USGS Stations Used to Estimate Discharge for Ten Lakes in LaGrange County					
Station ID	*Station Description*	*Drainage Area (mi^2)*	*Average Annual Discharge (cfs)*	*Period of Record (years)*	*cfs/mi^2*
04100222	N. Branch Elkhart River at Cosperville	142.0	138.0	20	0.972
04100252	Forker Creek Near Burr Oak	19.2	17.8	19	0.927
04100295	Rimmell Branch near Albion	10.7	11.1	8	1.037
Averages		14.95	14.45		0.979

Definitions

The annual discharge describes the volume of water that passes through the lake in one years time. The areal water load is equal to the annual discharge divided by the lake's surface area and describes the volume of water per unit of surface area. The flushing rate is the number of times per year the entire lake volume is replaced by inflowing water. The water renewal time is the inverse of the flushing rate and describes how many years it takes to replace the entire lake volume. The phosphorus retention coefficient describes what percentage of the phosphorus that enters the lake will remain, rather than pass through the outlet. This phosphorus retention coefficient was estimated by using the empirical equation developed by Kirchner and Dillon (1975).

4.1.1 Adams Lake

The Adams Lake watershed is 5.24 square miles in size including the surface area of Adams Lake. The estimated average annual discharge from the Adams Lake watershed is therefore 5.13 cubic feet per second, using the average cfs/mi^2 calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Adams Lake are presented in Table 4.2. See Section 4.1 for Definitions.

4.1.2 Atwood Lake

The Atwood Lake watershed is 1.21 square miles in size including the surface area of Atwood Lake. The estimated average annual discharge from the Atwood Lake watershed is therefore 1.19 cubic feet per second, using the average cfs/mi^2 calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Atwood Lake are presented in Table 4.3. See Section 4.1 for Definitions.

Table 4.2 Hydraulic Characteristics of Adams Lake	
Parameter	**Value**
Annual Discharge	4,577,503 m^3/yr
Areal Water Load	3.67 m/yr
Flushing Rate	0.56 times per year
Water Renewal Time	1.79 years
Phosphorus Retention Coefficient	71 percent

Table 4.3 Hydraulic Characteristics of Atwood Lake	
Parameter	**Value**
Annual Discharge	1,060,024 m^3/yr
Areal Water Load	1.54 m/yr
Flushing Rate	0.55 times per year
Water Renewal Time	1.82 years
Phosphorus Retention Coefficient	85 percent

4.1.3 Dallas Lake

The Dallas Lake watershed, including the surface area of Dallas Lake and the Adams, Atwood, Witmer, and Westler Lake watersheds, is 39.52 square miles in size. The estimated average annual discharge from the Dallas Lake watershed is therefore 38.69 cubic feet per second, using the average cfs/square miles calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Dallas Lake are presented in Table 4.4. See Section 4.1 for Definitions.

Table 4.4 Hydraulic Characteristics of Dallas Lake	
Parameter	**Value**
Annual Discharge	33,553,250 m^3/yr
Areal Water Load	30.17 m/yr
Flushing Rate	2.91 times per year
Water Renewal Time	0.34 years
Phosphorus Retention Coefficient	43 percent

4.1.4 Hackenburg Lake

The Hackenburg Lake watershed, including the surface area of Hackenburg Lake and the Oliver, Olin, Martin, Adams, Atwood, Witmer, Westler, and Dallas Lake watersheds, is 54.65 square miles in size. The estimated average annual discharge from the Hackenburg Lake watershed is therefore 53.51 cubic feet per second, using the average cfs/square miles calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Hackenburg Lake are presented in Table 4.5. See Section 4.1 for Definitions.

Table 4.5 Hydraulic Characteristics of Hackenburg Lake	
Parameter	**Value**
Annual Discharge	47,781,700 m^3/yr
Areal Water Load	281.12 m/yr
Flushing Rate	97.85 times per year
Water Renewal Time	0.01 years
Phosphorus Retention Coefficient	4 percent

4.1.5 Martin Lake

The Martin Lake watershed is 4.65 square miles in size including the surface area of Martin Lake. The estimated average annual discharge from the Martin Lake watershed is therefore 4.56 cubic feet per second, using the average cfs/square miles calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Martin Lake are presented in Table 4.6. See Section 4.1 for Definitions.

Table 4.6
Hydraulic Characteristics of Martin Lake

Parameter	Value
Annual Discharge	4,067,980 m^3/yr
Areal Water Load	38.66 m/yr
Flushing Rate	4.04 times per year
Water Renewal Time	0.25 years
Phosphorus Retention Coefficient	40 percent

4.1.6 Messick Lake

The Messick Lake watershed, which includes the surface area of Messick Lake and the Oliver, Olin, Martin, Adams, Atwood, Witmer, Westler, Dallas and Hackenburg Lake watersheds, is 55.64 square miles. The estimated average annual discharge from the Messick Lake watershed is therefore 54.47 cubic feet per second, using the average cfs/square miles calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Messick Lake are presented in Table 4.7. See Section 4.1 for Definitions.

Table 4.7 Hydraulic Characteristics of Messick Lake	
Parameter	**Value**
Annual Discharge	48,640,922 m^3/yr
Areal Water Load	176.76 m/yr
Flushing Rate	30.81 times per year
Water Renewal Time	0.03 years
Phosphorus Retention Coefficient	11 percent

4.1.7 Olin Lake

The Olin Lake watershed, including the surface area of Olin Lake and the Martin Lake watershed and is 5.57 square miles. The estimated average annual discharge from the Olin Lake watershed is therefore 5.45 cubic feet per second, using the average cfs/square miles calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Olin Lake are presented in Table 4.8. See Section 4.1 for Definitions.

Table 4.8 Hydraulic Characteristics of Olin Lake	
Parameter	**Value**
Annual Discharge	4,865,731 m^3/yr
Areal Water Load	11.67 m/yr
Flushing Rate	1.06 times per year
Water Renewal Time	0.94 years
Phosphorus Retention Coefficient	53 percent

4.1.8 Oliver Lake

The Oliver Lake watershed, including the surface area of Oliver Lake and the Olin and Martin Lake watersheds, is 10.85 square miles. The estimated average annual discharge from the Oliver Lake watershed is therefore 10.63 cubic feet per second, using the average cfs/square miles calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Oliver Lake are presented in Table 4.9. See Section 4.1 for Definitions.

Table 4.9 Hydraulic Characteristics of Oliver Lake	
Parameter	**Value**
Annual Discharge	9,489,679 m^3/yr
Areal Water Load	5.95 m/yr
Flushing Rate	0.54 times per year
Water Renewal Time	1.84 years
Phosphorus Retention Coefficient	63 percent

4.1.9 Westler Lake

The Westler Lake watershed, which includes the surface area of Westler Lake and the Adams, Atwood, and Westler Lake watersheds, is 37.63 square miles. The estimated average annual discharge from the Westler Lake watershed is therefore 36.84 cubic feet per second, using the average cfs/square miles calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Westler Lake are presented in Table 4.10. See Section 4.1 for Definitions.

Table 4.10 Hydraulic Characteristics of Westler Lake	
Parameter	**Value**
Annual Discharge	32,897,644 m^3/yr
Areal Water Load	92.38 m/yr
Flushing Rate	14.34 times per year
Water Renewal Time	0.07 years
Phosphorus Retention Coefficient	24 percent

4.1.10 Witmer Lake

The Witmer Lake watershed, which includes the surface area of Witmer Lake and the Adams and Atwood Lake watersheds, is 35.76 square miles. The estimated average annual discharge from the Witmer Lake watershed is therefore 35.01 cubic feet per second, using the average cfs/square miles calculated in Table 4.1. Based on this estimate, various hydraulic parameters for Witmer Lake are presented in Table 4.11. See Section 4.1 for Definitions.

Table 4.11
Hydraulic Characteristics of Witmer Lake

Parameter	Value
Annual Discharge	31,266,627 m^3/yr
Areal Water Load	37.87 m/yr
Flushing Rate	3.28 times per year
Water Renewal Time	0.31 years
Phosphorus Retention Coefficient	40 percent

4.2 Pollutant Budgets

Values for each of the terms in the universal soil loss equation (USLE, Section 4.2.2) are typically available from the local Soil Conservation Service or from other SCS publications. A weighted average value for RKLSP (soil loss in tons/acre/year) of 66.49 for agricultural lands, assuming a P factor (crop management factor) of 1.0, was obtained from data provided by the LaGrange County SCS office for each soil unit. Since 60 percent of the agricultural lands in crop with a P factor of 1.0 (personal communication, LaGrange SCS) and the remaining agricultural land is in pasture/fallow with a P factor of 0.3 (Woodland, 1975), the base RKLSP was multiplied by a P factor of 0.3 to yield a final RKLSP of 19.95 for agricultural land that is in pasture or fallow. The base RKLSP of 66.49 was multiplied by a P factor of 0.1 (Woodland, 1975) to yield an RKLSP for forested land of 6.65. For agricultural land uses, typical C factors (erosion control practice factors) for row crop, pasture land, and feed lot areas are 0.2, 0.125, and 1.0, respectively (LaGrange SCS, personal communication). A C factor for forested land of 0.003 was selected from Wischmeier and Smith (1978).

Calculated soil losses are presented in Table 4.12. A sediment delivery rate of 5 percent of the calculated soil loss was assumed.

Since the soils within the watershed are generally poorly suited for subsurface wastewater disposal, homes within this area can be considered to have a potential for impacting water quality due to septic leachate. In order to estimate the phosphorus and nitrogen inputs to the lake from septic systems, the following equations were used:

Phosphorus Load From Septic Systems	= (#homes) X (Avg People/Home) X (0.005 lb phosphorus/person*) X (days occupied/year).
Nitrogen Load From Septic Systems	= (#homes) X (Avg People/Home) X (0.028 lb nitrogen/person**) X (days occupied/year)

* phosphorus loading coefficient based on Indiana field data
** nitrogen loading coefficient is the median values reported by Reckhow (1980) for household wastewater.

Several assumptions were made to estimate a phosphorus and nitrogen loading to the lake. High risk homes were considered to be lakefront homes. The average number of occupants in year-round homes was considered to be 2.5, while the average number increases to 3.5 for seasonally used dwellings. Seasonal use was considered to be 98 days. Since soil has a certain capacity to treat wastewater, a soil retention factor was applied to the septic system loads (Canter and Knox, 1986). In selecting soil retention factors, local soil conditions near the ten LaGrange County lakes were considered. Soil retention of nutrients was considered to be higher for low risk homes. Numbers of homes were determined from USGS topographic maps and aerial photographs.

Total suspended solids loadings from precipitation were estimated from the average total suspended solids concentration in rainfall of 3 mg/L reported for a study in Virginia (F. X. Browne Associates, 1982) and the average annual rainfall in the study area of 33 inches (USGS, 1988).

Table 4.12
Calculated Soil Loss Coefficients

Land Use	USLE Parameter	Soil Loss	Delivery Ratio	Soil Delivery
Agriculture Row Crop	RKLSP = 66.49 C = 0.2	13.30 tons/ac/yr 33,392 kg/ha/yr	0.05	0.66 tons/ac/yr 1,639 kg/ha/yr
Agriculture Feedlots	RKLSP = 66.49 C = 1.0	66.49 tons/ac/yr 166,937 kg/ha/yr	0.05	3.32 tons/ac/yr 8,347 kg/ha/yr
Agriculture Pasture	RKLSP = 19.95 C = 0.125	2.49 tons/ac/yr 6,252 kg/ha/yr	0.05	0.12 tons/ac/yr 313 kg/ha/yr
Forest	RKLSP = 6.65 C = 0.003	0.02 tons/ac/yr 50 kg/ha/yr	0.05	0.001 tons/ac/yr 2.5 kg/ha/yr

4.2.1 Adams Lake - Point Source Pollutant Loads

There are no known point source discharges in the Adams Lake watershed.

4.2.2 Adams Lake - Nonpoint Source Pollutant Loads

<u>Watershed Pollutant Loads</u>

Nonpoint source pollutant loadings for lakes can be assessed through an extensive lake and stream monitoring program or through the use of the unit areal loading (UAL) approach (U.S. EPA, 1980). The monitoring approach requires that influent streams be analyzed for flow and pollutant concentrations during both wet and dry weather to determine average pollutant loadings. The unit areal loading approach is based on the premise that different types of land use contribute different quantities of pollutants through runoff.

The unit areal loading (UAL) approach is recommended for the estimation of pollutant inputs from nonpoint sources for watersheds where extensive stream monitoring data is not available (U.S. EPA, 1980). A combination of unit areal loadings for nutrient data and the universal soil loss equation (USLE) for the calculation of total suspended solids loads was used to develop nonpoint source pollutant budgets for Adams Lake.

Average nutrient export coefficients compiled by Reckhow et al. (1980) were used to estimate nonpoint pollutant loading from the various land uses within the watersheds. The coefficients reported by Reckhow et al. (1980) were also chosen for precipitation inputs of phosphorus and nitrogen. All precipitation inputs refer to direct precipitation on the lake surface.

The universal soil loss equation (USLE) was used to calculate sediment loadings to Adams Lake from agricultural and forested lands. This equation has the form:

$$A = RKLSCP \quad (1)$$

where A = soil loss (tons/acre/yr),
R = Number of erosion index units in a normal year's rain,
K = Soil erodibility factor,
L = Slope length factor,
S = Slope gradient factor,
C = Cropping management factor, and
P = Erosion control practice factor.

Table 4.13 presents the Unit Area Loading calculations for the Adams Lake direct watershed. There were five feedlots identified by field reconnaissance of F. X. Browne, Associates, Inc. and SCS personnel within the watershed. For a complete discussion of Unit Area Loading calculations, refer to Section 4.2.

Pollutant Loadings from Septic Leachate

Adams Lake has a total of 159 homes within 1,000 feet of the lake.

The factors used in the loading calculations and the results are presented in Table 4.14. For a complete discussion regarding pollutant loadings from septic systems, see Section 4.2.

Table 4.13
Unit Area Loadings for the Adams Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	124.6 hectares 307.8 acres	Total P Total N TSS		
Residential	70.5 hectares 174.3 acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	77.6 kg/yr (171.1 lbs/yr) 387.9 kg/yr (855.3 lbs/yr) 22,077.3 kg/yr (48,672.2 lbs/yr)
Forest	168.9 hectares 417.4 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	34.8 kg/yr (76.7 lbs/yr) 415.6 kg/yr (916.1 lbs/yr) 422.3 kg/yr (931.0 lbs/yr)
Agriculture Feedlots	1.2 hectares 3.0 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	296.2 kg/yr (653.1 lbs/yr) 3,548.9 kg/yr (7,824.1 lbs/yr) 10,133.7 kg/yr (22,341.1 lbs/yr)
Agriculture Row crops	606.4 hectares 1,498.3 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	1,358.2 kg/yr (2,994.4 lbs/yr) 5,457.2 kg/yr (12,031.1 lbs/yr) 993,816 kg/yr (2,190,990 lbs/yr)
Agriculture Pasture	259.9 hectares 642.1 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	197.5 kg/yr (435.4 lbs/yr) 1,580.0 kg/yr (3,488.3 lbs/yr) 81,338.2 kg/yr (179,320.1 lbs/yr)
Direct Precipitation on Lake Surface	124.6 hectares 308.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	56.1 kg/yr (123.7 lbs/yr) 2,615.0 kg/yr (5,765.1 lbs/yr) 1,140.5 kg/yr (2,514.3 lbs/yr)
Total Drainage Area	1,356 hectares 3,351 acres	Total P Total N TSS		2,020 kg/yr (4,454 lbs/yr) 14,005 kg/yr (30,875 lbs/yr) 1,108,928 kg/yr (2,444,769 lbs/yr)

Table 4.14
Estimated Loading to Adams Lake by Septic Systems

Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	6	Total Phosphorus Total Nitrogen	27 lbs/yr 153 lbs/yr	0.50 0.10	14 lbs/yr 138 lbs/yr
	Seasonal	4	Total Phosphorus Total Nitrogen	7 lbs/yr 38 lbs/yr	0.50 0.10	3 lbs/yr 35 lbs/yr
High Risk	Year-round	89	Total Phosphorus Total Nitrogen	406 lbs/yr 2,274 lbs/yr	0.25 0.05	304 lbs/yr 2,106 lbs/yr
	Seasonal	60	Total Phosphorus Total Nitrogen	102 lbs/yr 576 lbs/yr	0.25 0.05	77 lbs/yr 547 lbs/yr
TOTALS		159	Total Phosphorus Total Nitrogen			398 lbs/yr 2,880 lbs/yr

4.2.3 Adams Lake - Pollutant Budget Summary

The total pollutant budget for Adams Lake includes loadings from the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Direct nonpoint sources in the Adams Lake subwatershed contribute on an annual basis 1,964 kilograms of phosphorus (~,331 lbs), 11,390 kilograms of nitrogen (25,110 lbs) and 1,107,788 kilograms of suspended solids (2,442,255 lbs). Septic systems contribute an additional 181 kilograms of phosphorus (399 lbs) and 1,306 kilograms of nitrogen (2,880 lbs). As shown in Table 4.15, septic systems account for 8 percent of the annual phosphorus load and 8 percent of the annual nitrogen load to Adams Lake.

The major constituents affecting the water quality in Adams Lake are total phosphorus and total suspended solids. As shown in Figure 4.1, agricultural land uses contribute most of the phosphorus and suspended solid loadings to Adams Lake. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by the lake's surface, agricultural feedlots, forests, and residential areas.

Table 4.15
Pollutant Budget Summary for Adams Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus Nitrogen Suspended Solids	1,964.4 11,389.6 1,107,787.9	4,330.7 25,109.8 2,442,254.7	89.2 74.4 99.9
Septic Systems	Phosphorus Nitrogen Suspended Solids	180.9 1,306.4 0.0	398.8 2,880.2 0.0	8.3 8.5 0.0
Precipitation	Phosphorus Nitrogen Suspended Solids	56.1 2,615.0 1,140.5	123.7 5,765.1 2,514.3	2.5 17.2 0.1
TOTALS	Phosphorus Nitrogen Suspended Solids	2,201.4 15,311.1 1,108,928.4	4,853.1 33,755.1 2,444,769.0	100 100 100

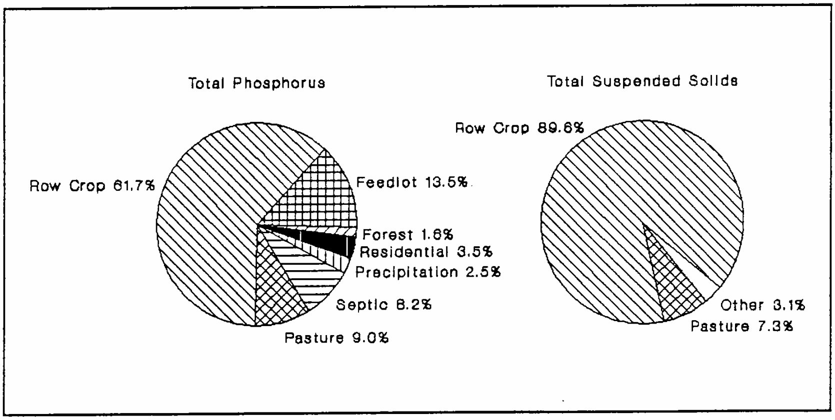


Figure 4.1 Percent total phosphorus and total suspended solid loadings to Adams Lake

4.2.4 Atwood Lake - Point Source Pollutant Loads

There are no known point source discharges in the Atwood Lake watershed.

4.2.5 Atwood Lake - Non-point Source Pollutant Loads

Watershed Pollutant Loads

Table 4.16 presents the Unit Area Loading calculations for the Atwood Lake direct watershed. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.2.

There were no feedlots identified by field reconnaissance of F. X. Browne Associates, Inc. and the SCS personnel within the watershed.

Table 4.16
Unit Area Loadings for the Atwood Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	17.4 hectares 43.0 acres	Total P Total N TSS		
Residential	--- hectares --- acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	--- kg/yr (--- lbs/yr) --- kg/yr (--- lbs/yr) --- kg/yr (--- lbs/yr)
Forest	39.8 hectares 98.4 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	8.2 kg/yr (18.1 lbs/yr) 97.9 kg/yr (215.9 lbs/yr) 99.5 kg/yr (219.4 lbs/yr)
Agriculture Feedlots	0 hectares 0 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	0 kg/yr (0 lbs/yr) 0 kg/yr (0 lbs/yr) 0 kg/yr (0 lbs/yr)
Agriculture Row crops	131.6 hectares 325.2 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	294.8 kg/yr (650.0 lbs/yr) 1,184.6 kg/yr (2,611.5 lbs/yr) 215,724 kg/yr (475,590 lbs/yr)
Agriculture Pasture	56.4 hectares 139.4 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	42.9 kg/yr (94.5 lbs/yr) 343.0 kg/yr (756.1 lbs/yr) 17,656 kg/yr (38,924 lbs/yr)
Direct Precipitation on Lake Surface	68.8 hectares 170.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	31.0 kg/yr (68.3 lbs/yr) 1,443.4 kg/yr (3,182.0 lbs/yr) 629.5 kg/yr (1,387.8 lbs/yr)
Total Drainage Area	314 hectares 776 acres	Total P Total N TSS		376.9 kg/yr (830.8 lbs/yr) 3,068.8 kg/yr (6,765.6 lbs/yr) 234,109 kg/yr (516,121.3 lbs/yr)

Note: --- denotes insignificant.

Pollutant Loadings from Septic Leachate

Atwood Lake has a total of 102 homes within 1,000 feet of the lake. Pollutant loadings from septic leachate was calculated for Atwood Lake and the results are shown in Table 4.17. For a complete discussion regarding pollutant loadings from septic leachate, refer to Section 4.2.

Table 4.17
Estimated Loading to Atwood Lake by Septic Systems

Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	3	Total Phosphorus Total Nitrogen	14 lbs/yr 77 lbs/yr	0.50 0.10	7 lbs/yr 69 lbs/yr
	Seasonal	3	Total Phosphorus Total Nitrogen	5 lbs/yr 29 lbs/yr	0.50 0.10	2 lbs/yr 26 lbs/yr
High Risk	Year-round	48	Total Phosphorus Total Nitrogen	219 lbs/yr 1,226 lbs/yr	0.25 0.05	164 lbs/yr 1,165 lbs/yr
	Seasonal	48	Total Phosphorus Total Nitrogen	82 lbs/yr 461 lbs/yr	0.25 0.05	62 lbs/yr 438 lbs/yr
TOTALS		102	Total Phosphorus Total Nitrogen			235 lbs/yr 1,698 lbs/yr

4.2.6 Atwood Lake - Pollutant Budget Summary

The total pollutant budget for Atwood Lake includes loadings from the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Direct nonpoint sources in the Atwood Lake watershed contribute on an annual basis 346 kilograms of phosphorus (763 lbs), 1,626 kilograms of nitrogen (3,584 lbs) and 233,479 kilograms of suspended solids (514,734 lbs). Septic systems contribute an additional 107 kilograms of phosphorus (235 lbs) and 770 kilograms of nitrogen (1,698 lbs). As shown in Table 4.18, septic systems account for 22 percent of the annual phosphorus load and 20 percent of the annual nitrogen load to Atwood Lake.

The major constituents affecting the water quality in Atwood Lake are total phosphorus and total suspended solids. As shown in Figure 4.2, agricultural land uses and leachate from septic systems contribute approximately 61 and 22 percent of the phosphorus loading to Atwood Lake, respectively. Approximately 92 percent of the suspended solid loadings to the lake is attributable to agricultural land uses. In the total suspended solids chart, the category "other" includes loadings from and precipitation directly intercepted by the lake's surface and forested areas.

Table 4.18
Pollutant Budget Summary for Atwood Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus Nitrogen Suspended Solids	345.9 1,625.5 233,479.2	762.6 3,583.5 514,733.5	71.5 42.3 99.7
Septic Systems	Phosphorus Nitrogen Suspended Solids	106.8 770.2 0.0	235.4 1,697.9 0.0	22.1 20.1 0.0
Precipitation	Phosphorus Nitrogen Suspended Solids	31.0 1,443.4 629.5	68.3 3,182.0 1,387.8	6.4 37.6 0.3
TOTALS	Phosphorus Nitrogen Suspended Solids	483.6 3,839.0 234,108.7	1,166.2 8,463.5 516,121.3	100 100 100

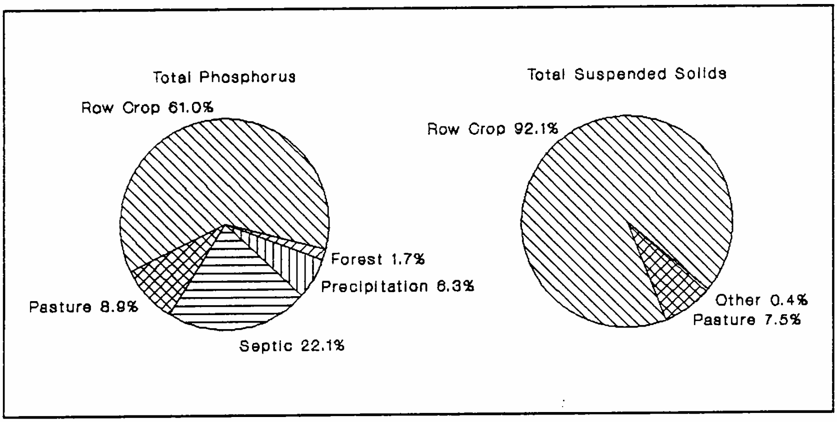


Figure 4.2 Percent total phosphorus and total suspended solid loadings for Atwood Lake

4.2.7 Dallas Lake - Point Source Pollutant Loads

There are no known point source discharges in the Dallas Lake watershed.

4.2.8 Dallas Lake - Non-point Source Pollutant Loads

Watershed Pollutant Loads

Table 4.19 presents the Unit Area Loading calculations for the Dallas direct watershed, not including the land that drains through Adams, Atwood, Witmer, and Westler Lakes. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.

There was one feedlot identified by field reconnaissance of F. X. Browne Associates, Inc. and the SCS personnel within the watershed.

Table 4.19
Unit Area Loadings for the Dallas Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	97.3 hectares 240.4 acres	Total P Total N TSS		
Residential	29.9 hectares 73.8 acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	32.9 kg/yr (72.4 lbs/yr) 164.3 kg/yr (362.2 lbs/yr) 9,349.2 kg/yr (20,611.4 lbs/yr)
Forest	2.8 hectares 6.8 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	0.6 kg/yr (1.3 lbs/yr) 6.8 kg/yr (15.0 lbs/yr) 6.9 kg/yr (15.2 lbs/vr)
Agriculture Feedlots	0.2 hectares 0.5 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	49.4 kg/yr (108.8 lbs/yr) 591.1 kg/yr (1,304.0 lbs/yr) 1,689.0 kg/yr (3,723.5 lbs/yr)
Agriculture Row crops	172.1 hectares 425.2 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	385.5 kg/yr (849.8 lbs/yr) 1,548.7 kg/yr (3,414.3 lbs/yr) 282,034 kg/yr (621,778 lbs/yr)
Agriculture Pasture	73.7 hectares 182.2 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	56.0 kg/yr (123.6 lbs/yr) 448.4 kg/yr (988.5 lbs/yr) 23,083 kg/yr (50,889 lbs/yr)
Direct Precipitation on Lake Surface	114.5 hectares 283.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	51.5 kg/yr (113.6 lbs/yr) 2,402.8 kg/yr (5,297.2 lbs/yr) 1,047.9 kg/yr (2,310.3 lbs/yr)
Total Drainage Area	490.5 hectares 1,212 acres	Total P Total N TSS		575.8 kg/yr (1,269.5 lbs/yr) 5,162.4 kg/yr (11,381.1 lbs/yr) 317,209 kg/yr (699,327 lbs/yr)

Pollutant Loadings from Septic Leachate

Dallas Lake has a total of 161 homes within 1,000 feet of the lake. Pollutant loadings from septic leachate was calculated for Dallas Lake and the results are shown in Table 4.20. For a complete discussion regarding pollutant loadings from septic leachate, refer to Section 4.2.

Table 4.20
Estimated Loading to Dallas Lake by Septic Systems

Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	18	Total Phosphorus Total Nitrogen	82 lbs/yr 460 lbs/yr	0.50 0.10	41 lbs/yr 414 lbs/yr
	Seasonal	9	Total Phosphorus Total Nitrogen	15 lbs/yr 86 lbs/yr	0.50 0.10	8 lbs/yr 78 lbs/yr
High Risk	Year-round	87	Total Phosphorus Total Nitrogen	397 lbs/yr 2,223 lbs/yr	0.25 0.05	297 lbs/yr 2,112 lbs/yr
	Seasonal	47	Total Phosphorus Total Nitrogen	81 lbs/yr 451 lbs/yr	0.25 0.05	60 lbs/yr 429 lbs/yr
TOTALS		161	Total Phosphorus Total Nitrogen			407 lbs/yr 3,032 lbs/yr

Pollutant Loadings from Upstream Lakes

A phosphorus retention coefficient of 0.24 was calculated for Westler Lake, which is directly upstream of Dallas Lake. This means that 24 percent of the phosphorus load to Westler Lake is retained by this system, while the remainder passes into Dallas Lake. The above retention coefficient has been applied to loading values from Westler Lake and the results are presented in the pollutant budget for Dallas Lake.

4.2.9 Dallas Lake - Pollutant Budget Summary

The total pollutant budget for Dallas Lake includes loadings from upstream watersheds, the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Upstream loadings are those point and nonpoint sources from upgradient watersheds, which eventually drain into Dallas Lake. On an annual basis, upstream loads contribute 6,734 kilograms of phosphorus (14,847 lbs.), 33,705 kilograms of nitrogen (75,533 lbs.), and 4,053,605 kilograms of suspended solids (8,936,671 lbs.). Direct nonpoint sources in the Dallas watershed, excluding the Adams, Atwood, Witmer, and Westler Lake subwatersheds, contribute on an annual basis 524 kilograms of phosphorus (1,156 lbs), 2,760 kilograms of nitrogen (6,084 lbs) and 316,161 kilograms of suspended solids (697,017 lbs.). Septic systems contribute an additional

185 kilograms of phosphorus (407 lbs) and 1,375 kilograms of nitrogen (3,032 lbs). As shown in Table 4.21, septic systems account for 2.5 percent of the annual phosphorus load and 3.3 percent of the annual nitrogen load to Dallas Lake.

The major constituents affecting the water quality in Dallas Lake are total phosphorus and total suspended solid loadings from the entire watershed. The entire Dallas Lake watershed includes the Adams, Atwood, Witmer and Westler subwatersheds. As shown in Figure 4.3, agricultural land uses contribute most of the phosphorus and suspended solid loadings to Dallas Lake.

In Figure 4.3, the percent loading for each category (except "septic" and "other") is based on the entire Dallas Lake watershed. The category "septic" only refers to septic systems located 1,000 feet from Dallas Lake. In the total phosphorus chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Dallas Lake, wastewater effluent entering Witmer Lake, leachate generated by upstream septic systems and all forested areas within the entire Dallas Lake watershed. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Dallas Lake, wastewater effluent entering Witmer Lake plus all agricultural feedlots, forests, and residential areas contained within the entire Dallas Lake watershed.

Table 4.21
Pollutant Budget Summary for Dallas Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus Nitrogen Suspended Solids	524.3 2,759.6 316,161.4	1,155.9 6,083.9 697,016.7	7.0 6.9 7.2
Septic Systems	Phosphorus Nitrogen Suspended Solids	184.6 1,375.4 0.0	406.9 3,032.2 0.0	2.5 3.3 0.0
Upstream Loads	Phosphorus Nitrogen Suspended Solids	6,734.3 33,704.6 4,053,605.2	14,846.6 75,532.7 8,936,671.1	89.8 83.8 92.7
Precipitation	Phosphorus Nitrogen Suspended Solids	51.5 2,402.8 1,047.9	113.6 5,297.2 2,310.3	0.7 6.0 0.0
TOTALS	Phosphorus Nitrogen Suspended Solids	7,494.7 40,242.4 4,370,814.5	16,523.0 89,946.0 9,635,998.1	100 100 100

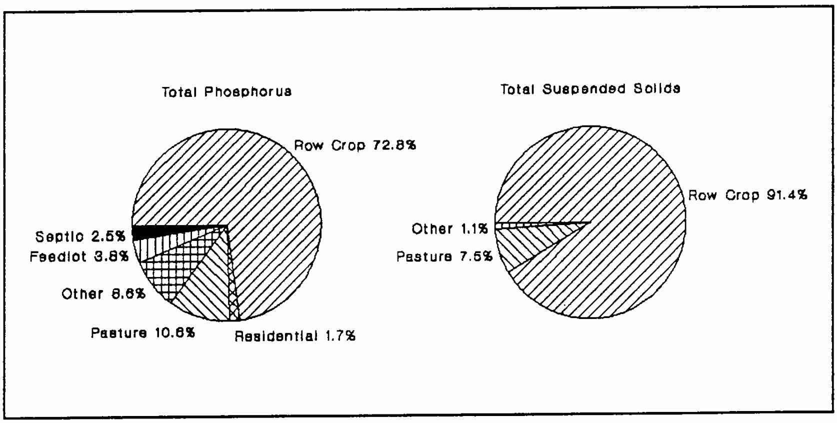


Figure 4.3 Percent total phosphorus and total suspended solid loadings for Dallas Lake

4.2.10 Hackenburg Lake - Point Source Pollutant Loads

There are no known point source discharges in the Hackenburg Lake watershed.

4.2.11 Hackenburg Lake - Non-point Source Pollutant Loads

Watershed Pollutant Loads

Table 4.22 presents the Unit Area Loading calculations for the Hackenburg direct watershed, not including Oliver, Olin, Martin, Adams, Atwood, Witmer, Westler, and Dallas Lakes. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.

There were four feedlots identified by field reconnaissance of F. X. Browne Associates, Inc. and SCS personnel within the watershed.

Table 4.22
Unit Area Loadings for the Hackenburg Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	204.0 hectares 504.2 acres	Total P Total N TSS		
Residential	27.3 hectares 67.4 acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	30.0 kg/yr (66.2 lbs/yr) 150.1 kg/yr (330.9 lbs/yr) 8,542.0 kg/yr (18,831.9 lbs/yr
Forest	108.5 hectares 268.2 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	22.4 kg/yr (49.3 lbs/yr) 267.0 kg/yr (588.6 lbs/yr) 271.3 kg/yr (598.2 lbs/yr)
Agriculture Feedlots	0.8 hectares 2.0 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	197.5 kg/yr (435.4 lbs/yr) 2,366.0 kg/yr (5,216.0 lbs/yr) 6,755.8 kg/yr (14,894.0 lbs/yr)
Agriculture Row crops	525.0 hectares 1,297.2 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	1,175.9 kg/yr (2,592.5 lbs/yr) 4,724.7 kg/yr (10,416.2 lbs/yr) 860,424 kg/yr (1,896,911 lbs/yr)
Agriculture Pasture	225.0 hectares 556.0 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	171.0 kg/yr (377.0 lbs/yr) 1,367.9 kg/yr (3,015.7 lbs/yr) 70,420.8 kg/yr (155,251.4 lbs/yr)
Direct Precipitation on Lake Surface	17.0 hectares 42.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	7.6 kg/yr (16.9 lbs/yr) 356.6 kg/yr (786.2 lbs/yr) 155.5 kg/yr (342.9 lbs/yr)
Total Drainage Area	1,107.6 hectares 2,737.0 acres	Total P Total N TSS		1,604.4 kg/yr (3,537.2 lbs/yr) 9,232.3 kg/yr (20,353.7 lbs/yr) 946,569.5 kg/yr (2,086,829 lbs/yr)

Pollutant Loadings from Septic Leachate

Hackenburg Lake has a total of 19 homes within 1,000 feet of the lake. Pollutant loadings from septic leachate was calculated for Hackenburg Lake and the results are shown in Table 4.23. For a complete discussion regarding pollutant loadings from septic leachate, refer to Section 4.2.

Table 4.23
Estimated Loading to Hackenburg Lake by Septic Systems

Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	4	Total Phosphorus Total Nitrogen	18 lbs/yr 102 lbs/yr	0.50 0.10	9 lbs/yr 92 lbs/yr
	Seasonal	6	Total Phosphorus Total Nitrogen	10 lbs/yr 58 lbs/yr	0.50 0.10	5 lbs/yr 52 lbs/yr
High Risk	Year-round	4	Total Phosphorus Total Nitrogen	18 lbs/yr 102 lbs/yr	0.25 0.05	14 lbs/yr 97 lbs/yr
	Seasonal	5	Total Phosphorus Total Nitrogen	8 lbs/yr 48 lbs/yr	0.25 0.05	6 lbs/yr 46 lbs/yr
TOTALS		19	Total Phosphorus Total Nitrogen			34 lbs/yr 287 lbs/yr

Pollutant Loading from Upstream Lakes

A phosphorus retention coefficient of 0.63 and 0.43 was calculated for Oliver and Dallas Lakes, respectively, which are directly upstream of Hackenburg Lake. This means that 63 percent of the phosphorus load to Oliver Lake is retained by this system, while 43 percent of the incoming load is retained by Dallas. The remainder of the phosphorus passes into Hackenburg Lake. The above retention coefficients have been applied to loading values from Oliver and Dallas Lakes and the results are presented in the pollutant budget for Hackenburg Lake.

4.2.12 Hackenburg Lake - Pollutant Budget Summary

The total pollutant budget for Hackenburg Lake includes loadings from upstream watersheds, the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Upstream loadings are those point and nonpoint sources from upgradient watersheds, which eventually drain into Hackenburg Lake. On an annual basis, upstream loads contribute 5,456 kilograms of phosphorus (12,028 lbs.), 31,040 kilograms of nitrogen (61,130 lbs.), and 3,126,176 kilograms of suspended solids (6,892,040 lbs.). Direct nonpoint sources in the Hackenburg watershed, excluding the Adams, Atwood, Witmer and Westler Lake subwatersheds, contribute on an annual basis 1,597 kilograms of phosphorus (3,520 lbs), 8,876 kilograms of nitrogen (19,567 lbs) and 946,414 kilograms of suspended solids (2,086,486 lbs). Septic systems contribute an additional 16 kilograms of phosphorus (34 lbs) and 130 kilograms of nitrogen (287 lbs). As shown in Table 4.24, septic systems account for 0.2 percent of the annual phosphorus load and 0.3 percent of the annual nitrogen load to Hackenburg Lake.

The major constituents affecting the water quality in Hackenburg Lake are total phosphorus and total suspended solid loadings from the entire watershed. The entire Hackenburg Lake watershed includes the Adams, Atwood, Witmer, Westler, Dallas, Martin, Olin, and Oliver subwatersheds. As shown in Figure 4.3, agricultural land uses contribute most of the phosphorus and suspended solid loadings to Hackenburg Lake.

In Figure 4.3, the percent loading for each category (except "septic" and "other") is based on the entire Hackenburg Lake watershed. The category "septic" only refers to septic systems located 1,000 feet from Hackenburg Lake. In the total phosphorus chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Hackenburg Lake, wastewater effluent entering Witmer Lake, leachate generated by upstream septic systems and all forested areas within the entire Hackenburg Lake watershed. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Hackenburg Lake, wastewater effluent entering Witmer Lake plus all agricultural feedlots, forests, and residential areas contained within the entire Hackenburg Lake watershed.

Table 4.24
Pollutant Budget Summary for Hackenburg Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus Nitrogen Suspended Solids	1,596.8 8,875.7 946,414.0	3,520.3 19,567.6 2,086,486.0	22.6 22.0 23.2
Septic Systems	Phosphorus Nitrogen Suspended Solids	15.6 130.0 0.0	34.4 286.6 0.0	0.2 0.3 0.0
Precipitation	Phosphorus Nitrogen Suspended Solids	7.6 356.6 155.5	16.9 786.2 342.9	0.1 0.9 0.0
Upstream Load	Phosphorus Nitrogen Suspended Solids	5,455.9 31,040.1 3,126,176.2	12,028.2 61,129.5 6,892,040.0	77.1 76.8 76.8
TOTALS	Phosphorus Nitrogen Suspended Solids	7,075.9 40,402.4 4,072,745.7	15,599.8 89,769.8 8,978,868.9	100 100 100

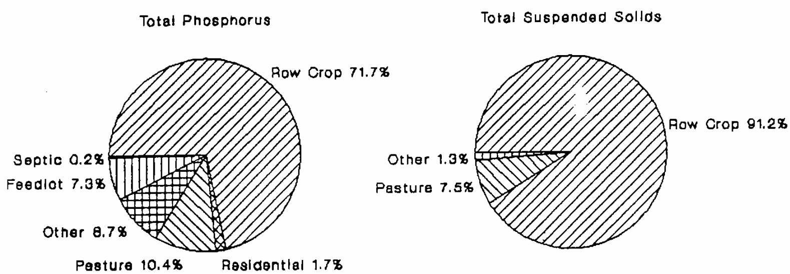


Figure 4.4 Percent total phosphorus and total suspended solid loadings for Hackenburg Lake

4.2.13 Martin Lake - Point Source Pollutant Loads

There are no known point source discharges in the Martin Lake watershed.

4.2.14 Martin Lake - Non-point Source Pollutant Loads

Table 4.25 presents the Unit Area Loading calculations for the Martin direct watershed. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.

There were four feedlots identified by field reconnaissance of F. X. Browne Associates, Inc. and SCS personnel within the watershed.

Table 4.25
Unit Area Loadings for the Martin Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	165.4 hectares 408.7 acres	Total P Total N TSS		
Residential	5.8 hectares 14.3 acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	6.3 kg/yr (14.0 lbs/yr) 31.7 kg/yr (69.9 lbs/yr) 1,805.6 kg/yr (3,980.8 lbs/yr)
Forest	111.0 hectares 274.4 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	22.9 kg/yr (50.4 lbs/yr) 273.1 kg/yr (602.2 lbs/yr) 277.6 kg/yr (611.9 lbs/yr)
Agriculture Feedlots	0.8 hectares 2.0 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	197.5 kg/yr (435.4 lbs/yr) 2,366.0 kg/yr (5,216.0 lbs/yr) 6,755.8 kg/yr (14,894.0 lbs/yr)
Agriculture Row crops	638.1 hectares 1,576.9 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	1,429.4 kg/yr (3,151.4 lbs/yr) 5,743.3 kg/yr (12,661.9 lbs/yr) 1,045,923 kg/yr (2,305,865 lbs/yr)
Agriculture Pasture	273.5 hectares 675.8 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	207.9 kg/yr (458.2 lbs/yr) 1,662.8 kg/yr (3,665.9 lbs/yr) 85,602.8 kg/yr (188,722 lbs/yr)
Direct Precipitation on Lake Surface	10.5 hectares 26.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	4.7 kg/yr (10.4 lbs/yr) 220.7 kg/yr (486.7 lbs/yr) 96.3 kg/yr (212.2 lbs/yr)
Total Drainage Area	1,205.2 hectares 2,978.0 acres	Total P Total N TSS		1,868.7 kg/yr (4,119.9 lbs/yr) 10,297.7 kg/yr (22,702.6 lbs/yr) 1,140,461 kg/yr (2,514,286 lbs/yr)

Pollutant Loadings from Septic Leachate

Martin Lake has a total of 17 homes within 1,000 feet of the lake. Pollutant loadings from septic leachate was calculated for Martin Lake and the results are shown in Table 4.26. For a complete discussion regarding pollutant loadings from septic leachate, refer to Section 4.2.

Table 4.26
Estimated Loading to Martin Lake by Septic Systems

Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	6	Total Phosphorus Total Nitrogen	27 lbs/yr 153 lbs/yr	0.50 0.10	14 lbs/yr 138 lbs/yr
	Seasonal	4	Total Phosphorus Total Nitrogen	7 lbs/yr 38 lbs/yr	0.50 0.10	3 lbs/yr 35 lbs/yr
High Risk	Year-round	4	Total Phosphorus Total Nitrogen	18 lbs/yr 102 lbs/yr	0.25 0.05	14 lbs/yr 97 lbs/yr
	Seasonal	3	Total Phosphorus Total Nitrogen	5 lbs/yr 29 lbs/yr	0.25 0.05	4 lbs/yr 27 lbs/yr
TOTALS		17	Total Phosphorus Total Nitrogen			35 lbs/yr 297 lbs/yr

4.2.15 Martin Lake - Pollutant Budget Summary

The total pollutant budget for Martin Lake includes loadings from the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Direct nonpoint sources in the Martin watershed contribute on an annual basis 1,864 kilograms of phosphorus (4,109 lbs), 10,077 kilograms of nitrogen (22,216 lbs) and 1,140,364 kilograms of suspended solids (2,514,074 lbs). Septic systems contribute an additional 16 kilograms of phosphorus (35 lbs) and 135 kilograms of nitrogen (297 lbs). As shown in Table 4.27, septic systems account for 0.8 percent of the annual phosphorus load and 1.3 percent of the annual nitrogen load to Martin Lake.

The major constituents affecting the water quality in Martin Lake are total phosphorus and total suspended solids. As shown in Figure 4.5, agricultural land uses contribute most of the phosphorus and suspended solid loadings to the lake. In the total phosphorus chart, the category "other" includes loadings from precipitation directly intercepted by the lake's surface and residential areas. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by the lake's surface, forests, agricultural feedlots and residential areas.

Table 4.27
Pollutant Budget Summary for Martin Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus	1,864.0	4,109.4	98.9
	Nitrogen	10,077.0	22,215.9	96.6
	Suspended Solids	1,140,364.4	2,514,073.7	100.0
Septic Systems	Phosphorus	15.7	34.7	0.8
	Nitrogen	134.7	297.0	1.3
	Suspended Solids	0.0	0.0	0.0
Precipitation	Phosphorus	4.7	10.4	0.3
	Nitrogen	220.7	486.7	2.1
	Suspended Solids	96.3	212.2	0.0
TOTALS	Phosphorus	1,892.3	4,171.7	100
	Nitrogen	10,429.5	22,993.0	100
	Suspended Solids	1,140,460.7	2,514,285.9	100

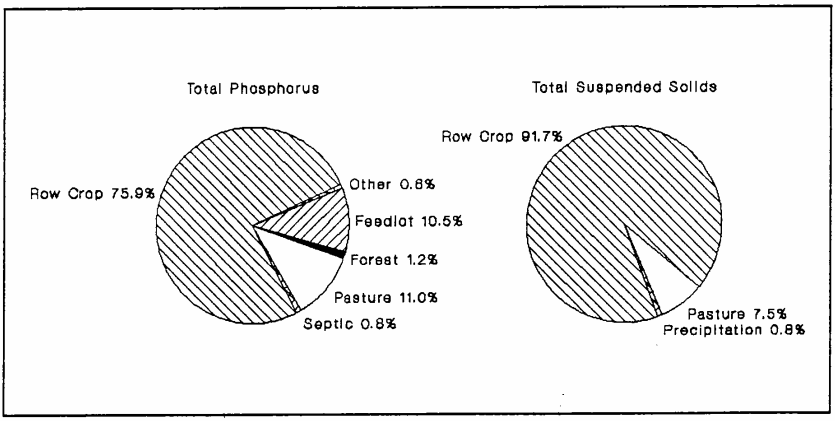


Figure 4.5 Percent total phosphorus and total suspended solid loadings for Martin Lake

4.2.16 Messick Lake - Point Source Pollutant Loads

There are no known point source discharges in the Messick Lake watershed.

4.2.17 Messick Lake - Non-point Source Pollutant Loads

Watershed Pollutant Loads

Table 4.28 presents the Unit Area Loading calculations for the Messick Lake direct watershed, not including Oliver, Olin, Martin, Adams, Atwood, Witmer, Westler, Dallas, and Hackenburg Lakes. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.

There were two feedlots identified by field reconnaissance of F. X. Browne Associates, Inc. and SCS personnel within the watershed.

Table 4.28
Unit Area Loadings for the Messick Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	13.6 hectares 33.6 acres	Total P Total N TSS		
Residential	29.4 hectares 72.7 acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	32.4 kg/yr (71.4 lbs/yr) 161.9 kg/yr (356.9 lbs/yr) 9,212.4 kg/yr (20,309.9 lbs/yr)
Forest	-- hectares -- acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	-- kg/yr (-- lbs/yr) -- kg/yr (-- lbs/yr) -- kg/yr (-- lbs/yr)
Agriculture Feedlots	0.4 hectares 1.0 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	98.7 kg/yr (217.7 lbs/yr) 1,183.0 kg/yr (2,608.0 lbs/yr) 3,377.9 kg/yr (7,447.0 lbs/yr)
Agriculture Row crops	128.5 hectares 317.6 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	287.9 kg/yr (634.6 lbs/yr) 1,156.6 kg/yr (2,549.9 lbs/yr) 210,631 kg/yr (464,363 lbs/yr)
Agriculture Pasture	55.1 hectares 136.1 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	41.9 kg/yr (92.3 lbs/yr) 334.9 kg/yr (738.3 lbs/yr) 17,239.0 kg/yr (38,005.5 lbs/yr)
Direct Precipitation on Lake Surface	27.5 hectares 68.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	12.4 kg/yr (27.3 lbs/yr) 577.3 kg/yr (1,272.8 lbs/yr) 251.8 kg/yr (555.1 lbs/yr)
Total Drainage Area	254.5 hectares 629.0 acres	Total P Total N TSS		473.2 kg/yr (1,043.3 lbs/yr) 3,413.7 kg/yr (7,525.9 lbs/yr) 240,713 kg/yr (530,680 lbs/yr)

Pollutant Loadings from Septic Leachate

Messick Lake has a total of 79 homes within 1,000 feet of the lake. Pollutant loadings from septic leachate was calculated for Messick Lake and the results are shown in Table 4.29. For a complete discussion regarding pollutant loadings from septic leachate, refer to Section 4.2.2.

Table 4.29
Estimated Loading to Messick Lake by Septic Systems

Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	15	Total Phosphorus Total Nitrogen	68 lbs/yr 383 lbs/yr	0.50 0.10	34 lbs/yr 345 lbs/yr
	Seasonal	9	Total Phosphorus Total Nitrogen	15 lbs/yr 86 lbs/yr	0.50 0.10	8 lbs/yr 78 lbs/yr
High Risk	Year-round	36	Total Phosphorus Total Nitrogen	164 lbs/yr 920 lbs/yr	0.25 0.05	123 lbs/yr 874 lbs/yr
	Seasonal	19	Total Phosphorus Total Nitrogen	32 lbs/yr 182 lbs/yr	0.25 0.05	24 lbs/yr 173 lbs/yr
TOTALS		79	Total Phosphorus Total Nitrogen			189 lbs/yr 1,470 lbs/yr

Pollutant Loading from Upstream Lakes

A phosphorus retention coefficient of 0.04 was calculated for Hackenburg Lake, which is directly upstream of Messick Lake. This means that 4 percent of the phosphorus load to Hackenburg Lake is retained by this system, while the remainder passes into Messick Lake. The above retention coefficient has been applied to loading values from Hackenburg Lake and the results are presented in the pollutant budget for Messick Lake.

4.2.18 Messick Lake - Pollutant Budget Summary

The total pollutant budget for Messick Lake includes loadings from upstream watersheds, the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Upstream loadings are those point and nonpoint sources from upgradient watersheds, which eventually drain into Messick Lake. On an annual basis, upstream loads contribute 6,794 kilograms of phosphorus (14,978 lbs.), 38,793 kilograms of nitrogen (86,194 lbs.), and 3,910,502 kilograms of suspended solids (8,621,182 lbs.). Direct nonpoint sources in the Messick watershed, excluding the Oliver, Olin, Martin, Adams, Atwood, Witmer, Dallas, and Hackenburg Lake subwatersheds, contribute on an annual basis 461 kilograms of phosphorus (1,016 lbs), 2,836 kilograms of nitrogen (6,253 lbs) and 240,461 kilograms of suspended solids (530,125 lbs). Septic systems contribute an additional 86 kilograms of phosphorus (190 lbs) and 667 kilograms of nitrogen (1,470 lbs). As shown in Table 4.30, septic systems account for 1.2 percent of the annual phosphorus load and 1.6 percent of the annual nitrogen load to Messick Lake.

The major constituents affecting the water quality in Messick Lake are total phosphorus and total suspended solid loadings from the entire watershed. The entire Messick Lake watershed includes the Adams, Atwood, Witmer, Westler, Dallas, Hackenburg, Martin, Olin, and Oliver subwatersheds. As shown in Figure 4.6, agricultural land uses contribute most of the phosphorus and suspended solid loadings to Hackenburg Lake.

In Figure 4.6, the percent loading for each category (except "septic" and "other") is based on the entire Messick Lake watershed. The category "septic" only refers to septic systems located 1,000 feet from Messick Lake. In the total phosphorus chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Messick Lake, wastewater effluent entering Witmer Lake, leachate generated by upstream septic systems and all forested areas within the entire Messick Lake watershed. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Messick Lake, wastewater effluent entering Witmer Lake plus all agricultural feedlots, forests, and residential areas contained within the entire Messick Lake watershed.

Table 4.30
Pollutant Budget Summary for Messick Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus Nitrogen Suspended Solids	460.8 2,836.3 240,460.7	1,016.0 6,253.0 530,125.1	6.2 6.6 5.8
Septic Systems	Phosphorus Nitrogen Suspended Solids	86.0 666.7 0.0	189.6 1,469.9 0.0	1.2 1.6 0.0
Precipitation	Phosphorus Nitrogen Suspended Solids	12.4 577.3 251.8	27.3 1,272.8 555.1	0.2 1.3 0.0
Upstream Load	Phosphorus Nitrogen Suspended Solids	6,794.0 38,792.9 3,910,501.8	14,978.3 86,193.7 8,621,182.2	92.4 90.5 94.2
TOTALS	Phosphorus Nitrogen Suspended Solids	7,353.3 42,873.3 4,151,214.2	16,211.2 95,189.4 9,151,862.4	100 100 100

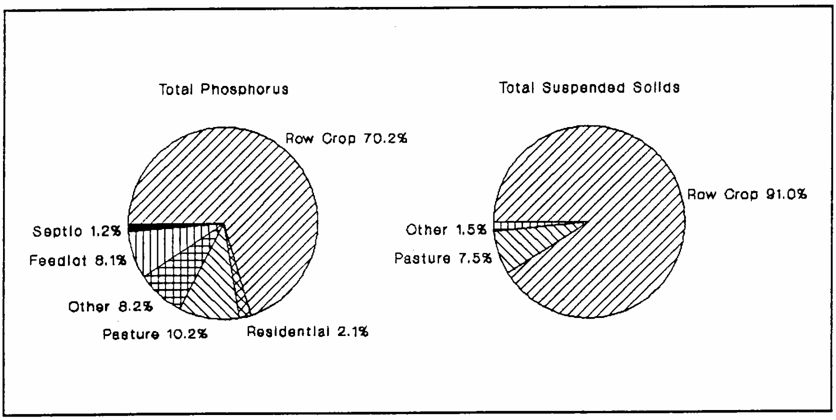


Figure 4.6 Percent total phosphorus and total suspended solid loadings for Messick Lake

4.2.19 Olin Lake - Point Source Pollutant Loads

There are no known point source discharges in the Olin Lake watershed.

4.2.20 Olin Lake - Non-point Source Pollutant Loads

Table 4.31 presents the Unit Area Loading calculations for the Olin Lake direct watershed, not including Martin Lake. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.

There was one feedlot identified by field reconnaissance of F. X. Browne Associates, Inc. and the SCS personnel within the watershed.

Table 4.31
Unit Area Loadings for the Olin Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	41.5 hectares 102.5 acres	Total P Total N TSS		
Residential	-- hectares -- acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	-- kg/yr (-- lbs/yr) -- kg/yr (-- lbs/yr) -- kg/yr (-- lbs/yr)
Forest	5.3 hectares 13.0 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	1.1 kg/yr (2.4 lbs/yr) 12.9 kg/yr (28.5 lbs/yr) 13.1 kg/yr (29.0 lbs/yr)
Agriculture Feedlots	0.2 hectares 0.5 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	49.4 kg/yr (108.8 lbs/yr) 591.5 kg/yr (1,304.0 lbs/yr) 1,689.0 kg/yr (3,723.5 lbs/yr)
Agriculture Row crops	103.4 hectares 255.5 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	231.6 kg/yr (510.6 lbs/yr) 930.6 kg/yr (2,051.5 lbs/yr) 169,466 kg/yr (373,608 lbs/yr)
Agriculture Pasture	44.3 hectares 109.5 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	33.7 kg/yr (74.2 lbs/yr) 269.4 kg/yr (594.0 lbs/yr) 13,869.8 kg/yr (30,577.7 lbs/yr)
Direct Precipitation on Lake Surface	41.7 hectares 103.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	18.8 kg/yr (41.4 lbs/yr) 874.5 kg/yr (1,927.9 lbs/yr) 381.4 kg/yr (840.8 lbs/yr)
Total Drainage Area	236.3 hectares 584.0 acres	Total P Total N TSS		334.5 kg/yr (737.4 lbs/yr) 2,678.9 kg/yr (5,906.0 lbs/yr) 185,419 kg/yr (408,779 lbs/yr)

Pollutant Loadings from Septic Leachate

No homes are within 1,000 feet of Olin Lake, therefore no pollutant loadings from septic leachate were calculated.

Pollutant Loading from Upstream Lakes

A phosphorus retention coefficient of 0.40 was been calculated for Martin Lake, which is directly upstream of Olin Lake. This means that 40 percent of the phosphorus load to Martin Lake is retained by this system, while the remainder passes into Olin Lake. The above retention coefficient has been applied to loading values from Martin Lake and the results are presented in the pollutant budget for Olin Lake.

4.2.21 Olin Lake - Pollutant Budget Summary

The total pollutant budget for Olin Lake includes loadings from upstream watersheds, the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Upstream loadings are those point and nonpoint sources from upgradient watersheds, which eventually drain into Olin Lake. On an annual basis, upstream loads contribute 1,135 kilograms of phosphorus (2,502 lbs.), 6,283 kilograms of nitrogen (13,852 lbs.), and 686,874 kilograms of suspended solids (1,514,298 lbs.). As shown in Table 4.32, direct nonpoint sources in the Olin watershed, excluding the Martin Lake subwatershed, contribute on an annual basis 316 kilograms of phosphorus (696 lbs), 1,804 kilograms of nitrogen (3,978 lbs) and 185,038 kilograms of suspended solids (407,938 lbs).

The major constituents affecting the water quality in Olin Lake are total phosphorus and total suspended solid loadings from the entire watershed. The entire Olin Lake watershed includes the Martin Lake subwatershed. As shown in Figure 4.7, agricultural land uses contribute most of the phosphorus and suspended solid loadings to Olin Lake.

In Figure 4.7, the percent loading for each category (except "precipitation" and "other") is based on the entire Olin Lake watershed. No "septic" category is shown since no septic systems are located within 1,000 feet of Olin Lake. The "precipitation" category refers to the amount of phosphorus contained in precipitation that is directly intercepted by the surface of Olin Lake. In the total phosphorus chart, the category "other" includes loadings from precipitation directly intercepted by Martin Lake, leachate generated by upstream septic systems and all forested / residential areas within the entire Olin Lake watershed. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by both Martin and Olin Lakes, plus all agricultural feedlots, forests, and residential areas contained within the entire Messick Lake watershed.

Table 4.32
Pollutant Budget Summary for Olin Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus Nitrogen Suspended Solids	315.7 1,804.4 185,037.6	696.1 3,978.0 407,938.1	21.5 20.1 21.2
Precipitation	Phosphorus Nitrogen Suspended Solids	18.8 874.5 381.4	41.4 1,927.9 840.8	1.3 9.8 0.0
Upstream Load	Phosphorus Nitrogen Suspended Solids	1,135.0 6,283.2 686,873.9	2,502.2 13,852.1 1,514,298.1	77.2 70.1 78.7
TOTALS	Phosphorus Nitrogen Suspended Solids	1,469.5 8,962.1 872,292.9	3,239.6 19,758.1 1,923,077.0	100 100 100

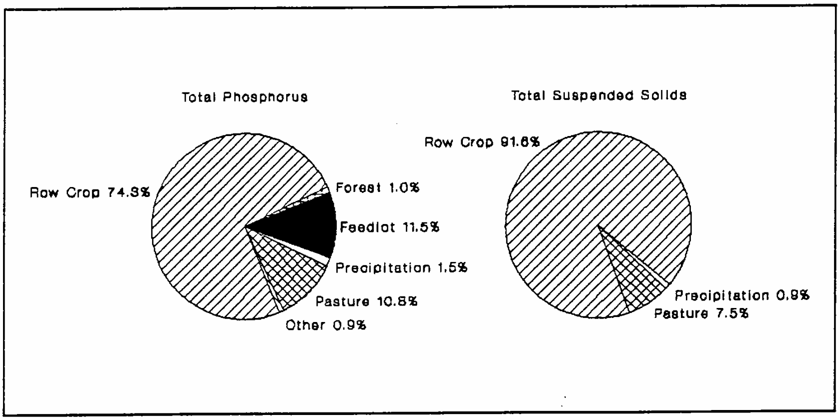


Figure 4.7 Percent total phosphorus and total suspended solid loadings for Olin Lake

4.2.22 Oliver Lake - Point Source Pollutant Loads

There are no known point source discharges in the Oliver Lake watershed.

4.2.23 Oliver Lake - Non-point Source Pollutant Loads

Watershed Pollutant Loads

Table 4.33 presents the Unit Area Loading calculations for the Oliver Lake direct watershed, not including Olin and Martin Lakes. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.

There were five feedlots identified by field reconnaissance of F. X. Browne Associates, Inc. and the SCS personnel within the watershed.

Table 4.33
Unit Area Loadings for the Oliver Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	24.2 hectares 59.8 acres	Total P Total N TSS		
Residential	48.9 hectares 120.9 acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	53.8 kg/yr (118.7 lbs/yr) 269.1 kg/yr (593.3 lbs/yr) 15,314.9 kg/yr (33,763.5 lbs/yr)
Forest	104.2 hectares 257.4 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	21.5 kg/yr (47.3 lbs/yr) 256.3 kg/yr (564.9 lbs/yr) 260.4 kg/yr (574.1 lbs/yr)
Agriculture Feedlots	1.4 hectares 3.5 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	345.6 kg/yr (761.9 lbs/yr) 4,140.4 kg/yr (9,128.1 lbs/yr) 11,822.7 kg/yr (26,064.6 lbs/yr)
Agriculture Row crops	722.2 hectares 1,784.6 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	1,617.7 kg/yr (3,566.5 lbs/yr) 6,499.8 kg/yr (14,329.7 lbs/yr) 1,183,693 kg/yr (2,609,597 lbs/yr)
Agriculture Pasture	309.5 hectares 764.8 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	235.2 kg/yr (518.6 lbs/yr) 1,881.9 kg/yr (4,148.8 lbs/yr) 96,878.6 kg/yr (213,580.7 lbs/yr)
Direct Precipitation on Lake Surface	159.4 hectares 394.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	71.8 kg/yr (158.2 lbs/yr) 3,345.2 kg/yr (7,374.9 lbs/yr) 1,458.9 kg/yr (3,216.4 lbs/yr)
Total Drainage Area	1,369.9 hectares 3,385.0 acres	Total P Total N TSS		2,345.6 kg/yr (5,171.2 lbs/yr) 16,392.7 kg/yr (36,139.6 lbs/yr) 1,309,428.4 kg/yr (2,886,796.0 lbs/yr)

Pollutant Loadings from Septic Leachate

Oliver Lake has a total of 172 homes within 1,000 feet of the lake. Pollutant loadings from septic leachate was calculated for Oliver Lake and the results are shown in Table 4.34. For a complete discussion regarding pollutant loadings from septic leachate, refer to Section 4.2.

Pollutant Loading from Upstream Lakes

A phosphorus retention coefficient of 0.53 was been calculated for Olin Lake, which is directly upstream of Oliver Lake. This means that 53 percent of the phosphorus load to Olin Lake is retained by this system, while the remainder passes into Oliver Lake. The above retention coefficient has been applied to loading values from Olin Lake and the results are presented in the pollutant budget for Oliver Lake.

Table 4.34
Estimated Loading to Oliver Lake by Septic Systems

Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	22	Total Phosphorus Total Nitrogen	100 lbs/yr 562 lbs/yr	0.50 0.10	50 lbs/yr 506 lbs/yr
	Seasonal	22	Total Phosphorus Total Nitrogen	38 lbs/yr 211 lbs/yr	0.50 0.10	19 lbs/yr 190 lbs/yr
High Risk	Year-round	64	Total Phosphorus Total Nitrogen	292 lbs/yr 1,635 lbs/yr	0.25 0.05	219 lbs/yr 1,553 lbs/yr
	Seasonal	64	Total Phosphorus Total Nitrogen	110 lbs/yr 615 lbs/yr	0.25 0.05	82 lbs/yr 584 lbs/yr
TOTALS		172	Total Phosphorus Total Nitrogen			370 lbs/yr 2,833 lbs/yr

4.2.24 Oliver Lake - Pollutant Budget Summary

The total pollutant budget for Oliver Lake includes loadings from upstream watersheds, the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Upstream loadings are those point and nonpoint sources from upgradient watersheds, which eventually drain into Oliver Lake. On an annual basis, upstream loads contribute 688 kilograms of phosphorus (1,517 lbs.), 4,196 kilograms of nitrogen (9,250 lbs.), and 408,391 kilograms of suspended solids (900,348 lbs.). Direct nonpoint sources in the Oliver watershed, excluding the Olin and Martin Lake subwatersheds, contribute on an annual basis 2,274 kilograms of phosphorus (5,013 lbs), 13,048 kilograms of nitrogen (28,765 lbs) and 1,307,970 kilograms of suspended solids

(2,883,580 lbs). Septic systems contribute an additional 168 kilograms of phosphorus (370 lbs) and 1,285 kilograms of nitrogen (2,833 lbs). As shown in Table 4.35, septic systems account for 5.2 percent of the annual phosphorus load and 5.9 percent of the annual nitrogen load to Oliver Lake.

The major constituents affecting the water quality in Oliver Lake are total phosphorus and total suspended solid loadings from the entire watershed. The entire Oliver Lake watershed includes the Martin and Olin Lake subwatersheds. As shown in Figure 4.8, agricultural land uses contribute most of the phosphorus and suspended solid loadings to Oliver Lake.

In Figure 4.8, the percent loading for each category (except "septic", "precipitation" and "other") is based on the entire Oliver Lake watershed. The "septic" category refers to the phosphorus loadings attributable to septic systems that are located within 1,000 feet of Oliver Lake. The "precipitation" category refers to the amount of phosphorus contained in precipitation that is directly intercepted by the surface of Oliver Lake. In the total phosphorus chart, the category "other" includes loadings from precipitation that is directly intercepted by upstream lakes plus leachate generated by upstream septic systems. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Oliver Lake, plus all agricultural feedlots, forests, and residential areas contained within the entire Oliver Lake watershed.

Table 4.35
Pollutant Budget Summary for Oliver Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus	2,273.9	5,013.0	71.0
	Nitrogen	13,047.5	28,764.8	59.7
	Suspended Solids	1,307,969.5	2,883,579.6	76.1
Septic Systems	Phosphorus	168.0	370.4	5.2
	Nitrogen	1,285.2	2,833.4	5.9
	Suspended Solids	0.0	0.0	0.0
Precipitation	Phosphorus	71.8	158.2	2.2
	Nitrogen	3,345.2	7,374.9	15.3
	Suspended Solids	1,458.9	3,216.4	0.1
Upstream Load	Phosphorus	688.0	1,516.7	21.5
	Nitrogen	4,195.9	9,250.4	19.2
	Suspended Solids	408,390.9	900,348.0	23.8
TOTALS	Phosphorus	3,201.6	7,058.3	100
	Nitrogen	21,873.8	48,223.4	100
	Suspended Solids	1,717,819.3	3,787,144.0	100

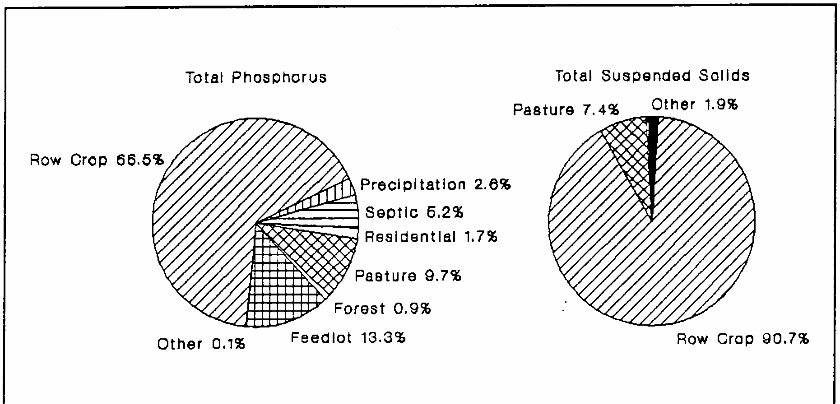


Figure 4.8 Percent total phosphorus and total suspended solid loadings to Oliver Lake

4.2.25 Westler Lake - Point Source Pollutant Loads

There are no known point source discharges in the Westler Lake watershed.

4.2.26 Westler Lake - Non-point Source Pollutant Loads

Table 4.36 presents the Unit Area Loading calculations for the Westler Lake direct watershed, not including Adams, Atwood, and Witmer Lakes. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.

There was one feedlot identified by field reconnaissance of F. X. Browne Associates, Inc. and SCS personnel within the watershed.

Table 4.36
Unit Area Loadings for the Westler Lake Direct Watershed

Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	-- hectares -- acres	Total P Total N TSS		
Residential	23.7 hectares 58.5 acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	26.0 kg/yr (57.4 lbs/yr) 130.2 kg/yr (287.0 lbs/yr) 7,408.3 kg/yr (16,332.5 lbs/yr)
Forest	63.4 hectares 156.5 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	13.1 kg/yr (28.8 lbs/yr) 155.8 kg/yr (343.6 lbs/yr) 158.4 kg/yr (349.2 lbs/yr)
Agriculture Feedlots	0.2 hectares 0.5 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	49.4 kg/yr (108.8 lbs/yr) 591.5 kg/yr (1,304.0 lbs/yr) 1,689.0 kg/yr (3,723.5 lbs/yr)
Agriculture Row crops	252.3 hectares 623.3 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	565.0 kg/yr (1,245.3 lbs/yr) 2,270.3 kg/yr (5,005.1 lbs/yr) 413,440.3 kg/yr (911,479.9 lbs/yr)
Agriculture Pasture	108.1 hectares 267.1 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	82.2 kg/yr (181.1 lbs/yr) 657.3 kg/yr (1,449.1 lbs/yr) 33,837.7 kg/yr (74,599.5 lbs/yr)
Direct Precipitation on Lake Surface	35.6 hectares 88.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	16.0 kg/yr (35.3 lbs/yr) 747.1 kg/yr (1,647.2 lbs/yr) 325.9 kg/yr (718.4 lbs/yr)
Total Drainage Area	483.2 hectares 1,194.0 acres	Total P Total N TSS		751.7 kg/yr (1,657.2 lbs/yr) 4,552.2 kg/yr (10,035.9 lbs/yr) 456,859.5 kg/yr (1,007,202.9 lbs/yr)

Pollutant Loadings from Septic Leachate

Westler Lake has a total of 145 homes within 1,000 feet of the lake. Pollutant loadings from septic leachate was calculated for Westler Lake and the results are shown in Table 4.37. For a complete discussion regarding pollutant loadings from septic leachate, refer to Section 4.2.

Table 4.37
Estimated Loading to Westler Lake by Septic Systems

Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	5	Total Phosphorus Total Nitrogen	23 lbs/yr 128 lbs/yr	0.50 0.10	12 lbs/yr 115 lbs/yr
	Seasonal	6	Total Phosphorus Total Nitrogen	10 lbs/yr 58 lbs/yr	0.50 0.10	5 lbs/yr 52 lbs/yr
High Risk	Year-round	60	Total Phosphorus Total Nitrogen	274 lbs/yr 1,533 lbs/yr	0.25 0.05	205 lbs/yr 1,456 lbs/yr
	Seasonal	74	Total Phosphorus Total Nitrogen	127 lbs/yr 711 lbs/yr	0.25 0.05	95 lbs/yr 675 lbs/yr
TOTALS		145	Total Phosphorus Total Nitrogen			317 lbs/yr 2,298 lbs/yr

Pollutant Loading from Upstream Lakes

A phosphorus retention coefficient of 0.40 was calculated for Witmer Lake, which is directly upstream of Westler Lake. This means that 40 percent of the phosphorus load to Witmer Lake is retained by this system, while the remainder passes into Westler Lake. The above retention coefficient has been applied to loading values from Witmer Lake and the results are presented in the pollutant budget for Westler Lake.

4.2.27 Westler Lake - Pollutant Budget Summary

The total pollutant budget for Westler Lake includes loadings from upstream watersheds, the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Upstream loadings are those point and nonpoint sources from upgradient watersheds, which eventually drain into Westler Lake. On an annual basis, upstream loads contribute 7,952 kilograms of phosphorus (17,532 lbs.), 39,419 kilograms of nitrogen (86,905 lbs.), and 4,868,999 kilograms of suspended solids (10,734,306 lbs.). Direct nonpoint sources in the Westler watershed, excluding the Adams, Atwood, and Witmer Lake subwatersheds, contribute on an annual basis 736 kilograms of phosphorus (1,622 lbs), 3,805 kilograms of nitrogen (8,389 lbs) and 456,534 kilograms of suspended solids (1,006,484 lbs). Septic systems contribute an additional

144 kilograms of phosphorus (317 lbs) and 1,042 kilograms of nitrogen (2,298 lbs). As shown in Table 4.38, septic systems account for 1.6 percent of the annual phosphorus load and 2.4 percent of the annual nitrogen load to Westler Lake.

The major constituents affecting the water quality in Westler Lake are total phosphorus and total suspended solid loadings from the entire watershed. The entire Westler Lake watershed includes the Adams, Atwood and Witmer subwatersheds. As shown in Figure 4.9, agricultural land uses contribute most of the phosphorus and suspended solid loadings to Westler Lake.

In Figure 4.9, the percent loading for each category (except "septic" and "other") is based on the entire Westler Lake watershed. The category "septic" only refers to septic systems located 1,000 feet from Westler Lake. In the total phosphorus chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Westler Lake, wastewater effluent entering Witmer Lake, leachate generated by upstream septic systems and all forested areas within the entire Westler Lake watershed. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Westler Lake, wastewater effluent entering Witmer Lake plus all agricultural feedlots, forests, and residential areas contained within the entire Westler Lake watershed.

Table 4.38
Pollutant Budget Summary for Westler Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Direct Nonpoint Sources	Phosphorus Nitrogen Suspended Solids	735.7 3,805.1 456,533.6	1,621.9 8,388.7 1,006,484.5	8.3 8.6 8.6
Septic Systems	Phosphorus Nitrogen Suspended Solids	143.8 1,042.5 0.0	317.0 2,298.3 0.0	1.6 2.4 0.0
Precipitation	Phosphorus Nitrogen Suspended Solids	16.0 16.0 325.9	35.3 35.3 718.4	0.2 0.0 0.0
Upstream Load	Phosphorus Nitrogen Suspended Solids	7,952.4 39,419.4 4,868,998.6	17,532.0 86,904.9 10,734,306.3	89.9 89.0 91.4
TOTALS	Phosphorus Nitrogen Suspended Solids	8,847.9 44,283.0 5,325,858.0	19,506.3 98,239.2 11,741,509.1	100 100 100

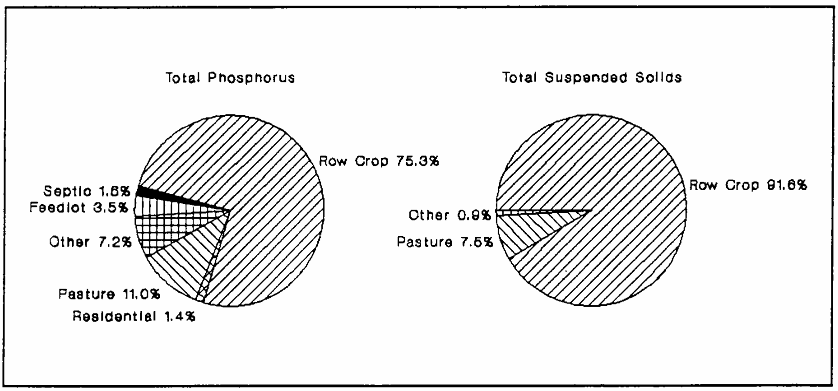


Figure 4.9 Percent total phosphorus and total suspended solid loadings for Westler Lake

4.2.28 Witmer Lake - Point Source Pollutant Loads

The Wolcottville Wastewater Treatment Plant is the only known point source in the Witmer Lake watershed. Based on average monthly discharge, estimated effluent phosphorus and nitrogen concentrations, and actual total suspended solids concentrations, the Wolcottville Wastewater Treatment Plant contributes 570.8 kg (1,258.5 lbs) of phosphorus, 1,141.7 kg (2,517.1 lbs) of nitrogen and 697.3 kg (1,537.2 lbs) of suspended solids to the annual pollutant budget of Witmer Lake.

4.2.29 Witmer Lake - Non-point Source Pollutant Loads

Watershed Pollutant Loads

Table 4.39 presents the Unit Area Loading calculations for the Witmer Lake direct watershed, not including Adams and Atwood Lakes. For a complete discussion regarding Unit Area Loading calculations, refer to Section 4.2.

There were five feedlots identified by field reconnaissance of F. X. Browne Associates, Inc. and SCS personnel within the watershed.

Pollutant Loadings from Septic Leachate

Witmer Lake has a total of 187 homes within 1,000 feet of the lake. Pollutant loadings from septic leachate was calculated for Witmer Lake and the results are shown in Table 4.40. For a complete discussion regarding pollutant loadings from septic leachate, refer to Section 4.2.

Table 4.39 Unit Area Loadings for the Witmer Lake Direct Watershed				
Land Use	Area	Parameter	Loading Coefficient	Annual Load
Wetlands/upstream waterbodies	753.0 hectares 1,860.8 acres	Total P Total N TSS		
Residential	130.5 hectares 322.6 acres	Total P Total N TSS	1.100 kg/ha/yr 5.500 kg/ha/yr 313 kg/ha/yr	143.6 kg/yr (316.6 lbs/yr) 718.0 kg/yr (1,582.9 lbs/yr) 40,861.0 kg/yr (90,083.2 lbs/yr)
Forest	410.3 hectares 1,013.8 acres	Total P Total N TSS	0.206 kg/ha/yr 2.460 kg/ha/yr 2.5 kg/ha/yr	84.5 kg/yr (186.3 lbs/yr) 1,009.3 kg/yr (2,225.1 lbs/yr) 1,025.7 kg/yr (2,261.2 lbs/yr)
Agriculture Feedlots	1.4 hectares 3.5 acres	Total P Total N TSS	244.0 kg/ha/yr 2,923.2 kg/ha/yr 8,347 kg/ha/yr	345.6 kg/yr (761.9 lbs/yr) 4,140.4 kg/yr (9,128.1 lbs/yr) 11,822.7 kg/yr (26,064.6 lbs/yr)
Agriculture Row crops	4,350.4 hectares 10,750.1 acres	Total P Total N TSS	2.240 kg/ha/yr 9.000 kg/ha/yr 1,639 kg/ha/yr	9,745.0 kg/yr (21,483.9 lbs/yr) 39,153.8 kg/yr (86,319.4 lbs/yr) 7,130,347.9 kg/yr (15,719,729.0 lbs/yr)
Agriculture Pasture	1,864.5 hectares 4,607.2 acres	Total P Total N TSS	0.760 kg/ha/yr 6.080 kg/ha/yr 313 kg/ha/yr	1,417.0 kg/yr (3,123.9 lbs/yr) 11,336.0 kg/yr (24,991.5 lbs/yr) 583,578.5 kg/yr (1,286,570.7 lbs/yr)
Direct Precipitation on Lake Surface	82.6 hectares 204.0 acres	Total P Total N TSS	0.45 kg/ha/yr 20.98 kg/ha/yr 9.15 kg/ha/yr	37.2 kg/yr (81.9 lbs/yr) 1,732.0 kg/yr (3,818.5 lbs/yr) 755.4 kg/yr (1,665.3 lbs/yr)
Total Drainage Area	7,592.7 hectares 18,762.0 acres	Total P Total N TSS		11,772.8 kg/yr (25,954.6 lbs/yr) 58,089.5 kg/yr (128,065.5 lbs/yr) 7,768,391.3 kg/yr (17,126,374.0 lbs/yr)

Table 4.40 Estimated Loading to Witmer Lake by Septic Systems						
Dwelling Class		Number of Units	Parameter	Septic Load	Soil Retention Coefficient	Nutrient Load to Lake
Low Risk	Year-round	0	Total Phosphorus Total Nitrogen	0 lbs/yr 0 lbs/yr	0.50 0.10	0 lbs/yr 0 lbs/yr
	Seasonal	1	Total Phosphorus Total Nitrogen	2 lbs/yr 10 lbs/yr	0.50 0.10	1 lbs/yr 9 lbs/yr
High Risk	Year-round	112	Total Phosphorus Total Nitrogen	511 lbs/yr 2,862 lbs/yr	0.25 0.05	383 lbs/yr 2,718 lbs/yr
	Seasonal	74	Total Phosphorus Total Nitrogen	127 lbs/yr 711 lbs/yr	0.25 0.05	95 lbs/yr 675 lbs/yr
TOTALS		187	Total Phosphorus Total Nitrogen			479 lbs/yr 3,402 lbs/yr

Pollutant Loading from Upstream Lakes

A phosphorus retention coefficient of 0.71 and 0.85 have been calculated for Adams and Atwood Lakes, which are directly upstream of Witmer Lake. This means that 71% of the phosphorus load to Adams Lake is retained by this system, while 85% of the load is retained by Atwood Lake. The remainder passes into Witmer Lake. The above retention coefficients have been applied to loading values from Adams and Atwood Lakes and the results are presented in the pollutant budget for Witmer Lake.

4.2.30 Witmer Lake - Pollutant Budget Summary

The total pollutant budget for Witmer Lake includes loadings from upstream watersheds, the direct watershed as nonpoint sources, septic systems near the lake, and precipitation intercepted by the lake's surface. Upstream loadings are those point and nonpoint sources from upgradient watersheds, which eventually drain into Witmer Lake. On an annual basis, upstream loads contribute 709 kilograms of phosphorus (1,563 lbs.), 5,003 kilograms of nitrogen (11,029 lbs.), and 355,583 kilograms of suspended solids (783,926 lbs.). Direct nonpoint sources in the Witmer watershed, excluding the Adams and Atwood Lake subwatersheds, contribute on an annual basis 11,736 kilograms of phosphorus (25,873 lbs), 56,358 kilograms of nitrogen (124,247 lbs) and 7,767,636 kilograms of suspended solids (17,124,709 lbs). Septic systems contribute an additional 217 kilograms of phosphorus (479 lbs) and 1,543 kilograms of nitrogen (3,402 lbs). As shown in Table 4.41, septic systems account for 1.6 percent of the annual phosphorus load and 2.3 percent of the annual nitrogen load to Witmer Lake.

The major constituents affecting the water quality in Westler Lake are total phosphorus and total suspended solid loadings from the entire watershed. The entire Westler Lake watershed includes the Adams and Atwood subwatersheds. As shown in Figure 4.10, agricultural land uses contribute most of the phosphorus and suspended solid loadings to Witmer Lake.

In Figure 4.10, the percent loading for each category (except "septic" and "other") is based on the entire Witmer Lake watershed. The category "septic" only refers to septic systems located 1,000 feet from Witmer Lake. In the total phosphorus chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Witmer Lake, wastewater effluent entering Witmer Lake, leachate generated by upstream septic systems and all forested areas within the entire Witmer Lake watershed. In the total suspended solids chart, the category "other" includes loadings from precipitation directly intercepted by all upstream lakes and Witmer Lake, wastewater effluent entering Witmer Lake plus all agricultural feedlots, forests, and residential areas contained within the entire Witmer Lake watershed.

Table 4.41
Pollutant Budget Summary for Witmer Lake Watershed

Category	Parameter	Loading kg/year	Loading lbs/year	Loading Percent
Point Sources	Phosphorus	570.8	1,258.4	4.3
	Nitrogen	1,141.7	2,517.0	1.7
	Suspended Solids	697.3	1,537.3	0.0
Direct Nonpoint Sources	Phosphorus	11,735.7	25,872.7	88.5
	Nitrogen	56,357.5	124,247.0	85.8
	Suspended Solids	7,767,635.9	17,124,708.7	95.6
Septic Systems	Phosphorus	217.4	479.3	1.6
	Nitrogen	1,543.3	3,402.3	2.3
	Suspended Solids	0.0	0.0	0.0
Precipitation	Phosphorus	37.2	81.9	0.3
	Nitrogen	1,732.0	3,818.5	2.6
	Suspended Solids	755.4	1,665.3	0.0
Upstream Load	Phosphorus	708.8	1,562.6	5.3
	Nitrogen	5,002.8	11,029.3	7.6
	Suspended Solids	355,582.7	783,925.8	4.4
TOTALS	Phosphorus	13,269.8	29,254.9	100
	Nitrogen	65,777.3	145,014.2	100
	Suspended Solids	8,124,671.3	17,911,837.1	100

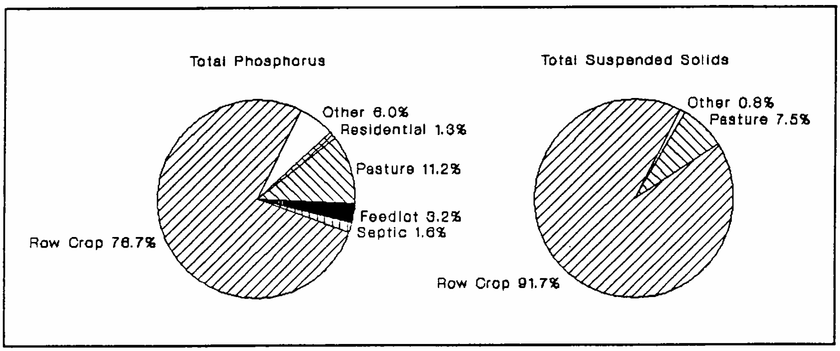


Figure 4.10 Percent total phosphorus & total suspended solid loading in Witmer Lake

4.3 Phosphorus Modeling

Estimates of the maximum permissible pollutant loading to a lake can be calculated using the widely used Dillon and Rigler (1975) and Vollenweider (1977) models. The Dillon and Rigler model predicts annual mean total phosphorus concentrations using the formula:

$$TP = L(1\text{-}R)/pz$$

where TP = annual mean phosphorus concentration (g/m3)
L = areal phosphorus loading (g/m2/yr)
R = phosphorus retention coefficient
p = flushing rate (times/yr)
z = mean depth (m)

Using previously calculated values, we can predict the annual mean phosphorus concentration in the ten lakes in LaGrange County. The phosphorus loading can then be varied until we reach an acceptable total phosphorus level, which is described by Vollenweider (1977) as 0.02 g/m3. Comparing this to the estimated current phosphorus load, we can come up with the percent reduction needed to improve the lake's water quality.

The phosphorus model provides the best results when both hydrologic and nutrient budgets for a given lake are determined by intensive field investigations. Since intensive field investigations were beyond the scope of this study, hydrologic and nutrient budgets were estimated as discussed in Section 4.1 and 4.2. From these estimated budgets, flushing rates and areal phosphorus loadings were determined for each of the ten lakes. From the above model, the predicted total phosphorus concentration represents the annual average in-lake total phosphorus concentration. These predicted total phosphorus concentrations are not directly comparable to the total phosphorus concentration for one sample date.

4.3.1 Adams Lake

Substituting values from Section 4.1.1 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Adams Lake of 0.11 mg/L, which is greater than the one-day measured average of 0.05 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 82 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, the phosphorus loading to lake must be reduced by 60 percent to improve water quality to a mesotrophic condition. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Adams Lake.

4.3.2 Atwood Lake

Substituting values from Section 4.1.2 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Atwood Lake of 0.06 mg/L, which is greater than the one-day measured average of 0.04 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 63 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, the phosphorus loading to the lake must be reduced by 50 percent to improve water quality to a mesotrophic condition. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Atwood Lake.

4.3.3 Dallas Lake

Substituting values from Section 4.1.3 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Dallas Lake of 0.11 mg/L, which is greater than the one-day measured average of 0.05 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 82 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, the phosphorus loading to the lake must be reduced by 60 percent to improve water quality to a mesotrophic condition. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Dallas Lake.

4.3.4 Hackenburg Lake

Substituting values from Section 4.1.4 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Hackenburg Lake of 0.11 mg/L, which is less than the one-day measured average of 0.46 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 81 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, the phosphorus loading to the lake must be reduced by 96 percent to improve water quality to a mesotrophic condition. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Hackenburg Lake.

4.3.5 Martin Lake

Substituting values from Section 4.1.5 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Martin Lake of 0.26 mg/L, which is greater than the one-day measured average of 0.05 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 92 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, the phosphorus loading to the lake must be reduced by 60 percent to improve water quality to a mesotrophic condition. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Martin Lake.

4.3.6 Messick Lake

Substituting values from Section 4.1.6 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Messick Lake of 0.11 mg/L, which compares favorably with the one-day measured average of 0.19 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 82 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, the phosphorus loading to the lake must be reduced by 90 percent to improve water quality to a mesotrophic condition. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Messick Lake.

4.3.7 Olin Lake

Substituting values from Section 4.1.7 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Olin Lake of 0.13 mg/L, which is greater than the one-day measured average of 0.01 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 85 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, no reductions in the phosphorus loading is required since the water quality is already mesotrophic. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Olin Lake.

4.3.8 Oliver Lake

Substituting values from Section 4.1.8 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Oliver Lake of 0.11 mg/L, which is greater than the one-day measured average of 0.02 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 81 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, no reductions in the phosphorus loading is required since the water quality is already mesotrophic. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Oliver Lake.

4.3.9 Westler Lake

Substituting values from Section 4.1.9 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Westler Lake of 0.21 mg/L, which compares favorably with the one-day measured average of 0.20 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 90 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, the phosphorus loading to the lake must be reduced by 90 percent to improve water quality to a mesotrophic condition. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Westler Lake.

4.3.10 Witmer Lake

Substituting values from Section 4.1.10 and the nutrient loading sections into the Dillon and Rigler equation, we get a predicted mean total phosphorus concentration for Witmer Lake of 0.27 mg/L, which is greater than the one-day measured average of 0.16 mg/L. If the predicted mean total phosphorus concentration is correct, the phosphorus loading to the lake must be reduced by 93 percent to improve water quality to a mesotrophic condition. If the one-day measured average concentration is representative of average summer conditions, the phosphorus loading to the lake must be reduced by 88 percent to improve water quality to a mesotrophic condition. In any case, a reduction in the phosphorus loading to the lake would help preserve and improve the water quality of Witmer Lake.

5.0 Evaluation of Alternatives

Management alternatives for the ten lakes in LaGrange County were divided into two categories: watershed management alternatives and in-lake management alternatives. The first priority in all management programs is to determine whether watershed management practices can be implemented to reduce the pollutants entering the lake. Because nonpoint source pollutants account for a high percentage of the nutrient and sediment loading to each of the ten lakes, it is critical that lake restoration focuses on watershed controls. If watershed controls are not implemented, then the recommended in-lake restoration will have little effect towards improving water quality.

The following sections discuss the in-lake and watershed restoration methods that are applicable to the ten lakes in LaGrange County. A list of potential in-lake management and watershed management alternatives are listed below:

A. In-lake Management Alternatives

1. Lake Aeration
   a. Aeration
   b. Mechanical Circulation

2. Lake Deepening
   a. Dredging
   b. Drawdown and Sediment Consolidation
   c. Raise Lake Surface Elevation

3. Other Physical Controls
   a. Harvesting of Nuisance Biomass
   b. Water Level Fluctuation
   c. Habitat Manipulation
   d. Covering Bottom Sediments to Control Macrophytes

4. Chemical Controls
   a. Algicides
   b. Herbicides
   c. Pesticides

5. Biological Controls
   a. Predator-prey relationships
   b. Intra- and inter-specific manipulation
   c. Pathologic reactions

6. **In-lake Schemes to Accelerate Nutrient Outflow or Prevent Recycling**
   a. Dredging for nutrient control
   b. Nutrient Inactivation/Precipitation
   c. Dilution/flushing
   d. Biotic harvesting for nutrient removal
   e. Selective discharge from impoundments
   f. Sediment exposure and desiccation
   g. Lake bottom sealing

B. **Watershed Management Alternatives**
   1. Agriculture Management Practices
   2. Homeowner Management Practices
   3. Wastewater Management Practices
   4. Homeowner Management Practices
   5. Streambank Erosion Control
   6. Roadway Erosion Control
   7. Development of Model Ordinances

The following criteria were used in the evaluation of potential management alternatives:

Effectiveness:	how well a specific management practice meets its goal
Longevity:	reflects the duration of treatment effectiveness
Confidence:	refers to the number and quality of reports and studies supporting the effectiveness rating given to a specific treatment
Applicability:	refers to whether or not the treatment directly affects the cause of the problem and whether it is suitable for the region in which it is considered for application
Potential for Negative Impacts:	an evaluation should be made to insure that a proposed management practice does not cause a negative impact on the lake ecosystem
Capital Costs:	standard approaches should be used to evaluate the cost- effectiveness of various alternatives
Operation and Maintenance Costs:	these costs should be evaluated to help determine the cost-effectiveness of each management alternative

5.1 In-Lake Restoration Methods

This section discusses some of the more widely accepted in-lake restoration methods for improving water quality. These techniques are aimed at controlling aquatic vegetation and algae, improving dissolved oxygen levels, and/or minimizing the internal phosphorus loading from sediments. Each technique is discussed in terms of the basic principles and its appropriateness for use in the Indiana lakes. It must be kept in mind that in-lake restoration alone will not result in a noticeable improvement in water quality due to the high watershed pollutant loads. Recreational benefits may result, however, by managing macrophyte densities.

5.1.1 Lake Aeration

Aeration has been widely-used as a restoration measure for lakes where summer hypolimnetic oxygen depletion and/or winter-kill are of major concern. Aeration can be divided into two categories: those methods which destratify (mix) the lake water column and circulate the entire lake and those methods which aerate the hypolimnion (deep water layer) without destratifying the lake. Both methods are based on the principle that if you increase the dissolved oxygen concentration in a lake, you will provide additional habitat for fish while decreasing the release of phosphorus from the sediments that occurs under anoxic (low dissolved oxygen) conditions.

Some studies have shown that algae levels may be controlled by destratifying a lake, though most recent works on larger lakes indicate that this effect is only temporary. After a few seasons, algae concentrations may actually increase and bluegreen algae can continue to dominate. Aeration by destratification works by bubbling air from the lake bottom, causing the water column to circulate.

Hypolimnetic aerators, which do not destratify a lake, work by lifting and aerating bottom water in a closed chamber and circulating the aerated water back into the hypolimnion.

Based on the morphology and the water quality characteristics of the ten Indiana lakes, hypolimnetic aeration was selected over destratifying systems because as stated above, these systems would provide a coldwater habitat for coldwater fish species, reduce internal phosphorus loadings from lake sediments, and greatly reduce the risk of nutrient recirculation. For each of the Indiana lakes, the anoxic volume of water was calculated from existing bathymetric maps and dissolved oxygen profiles obtained in the field.

In sizing hypolimnetic aeration systems, an oxygen depletion rate is usually determined from multiple dissolved oxygen profiles recorded throughout the spring and summer months. Since only one dissolved oxygen profile was monitored for each of the lakes, the dissolved oxygen depletion rate was assumed to be 0.3 mg/L per day. The oxygen demand for each lake was determined by multiplying the hypolimnetic volume by the oxygen depletion rate. The actual aerator design was based on lake size and lake shape, and the required oxygen supply rate. The oxygen supply rate is twice the oxygen demand to insure an adequate supply of oxygen.

For each of the ten LaGrange County lakes, the hypolimnetic aeration sizing requirements plus associated equipment and operational costs are described below.

Adams Lake

The anoxic volume of water for Adams Lake was estimated at 5.12 million cubic meters and would require approximately 3,072 kilograms of oxygen per day (oxygen supply rate). Based on the lake morphology and the required oxygen supply rate, six aerators and two (50) horse powered air compressors would be needed. The estimated project cost is $464,850, which includes all major hardware, installation, start-up costs, labor, freight, diving and special equipment expenses. The above project cost does not include housing structures for the compressors, bringing electric power to the site, or the trenching of air lines. Assuming 150 days of operation at $0.08 per kilowatt-hour, the annual operational cost is estimated at $18,749.

Based on the high estimated project and annual operating costs, hypolimnetic aeration does not appear to be a cost-effective management alternative for Adams Lake.

Atwood Lake

The anoxic volume of water for Atwood Lake was estimated at 0.57 million cubic meters and would require approximately 343 kilograms of oxygen per day (oxygen supply rate). Based on the lake morphology and the required oxygen supply rate, one aerator and one (15) horse powered air compressor would be needed. The estimated project cost is $82,850, which includes all major hardware, installation, start-up costs, labor, freight, diving and special equipment expenses. The above project cost does not include housing structures for the compressor, bringing electric power to the site, or the trenching of air lines. Assuming 150 days of operation at $0.08 per kilowatt-hour, the annual operational cost is estimated at $2,938.

Based on the relatively low estimated project and annual operating costs, hypolimnetic aeration may be a viable management alternative for Atwood Lake.

Dallas Lake

The anoxic volume of water for Dallas Lake was estimated at 6.86 million cubic meters and would require approximately 4,117 kilograms of oxygen per day (oxygen supply rate). Based on the lake morphology and the required oxygen supply rate, five aerators and two (60) horse powered air compressors would be needed. The estimated project cost is $409,200 which includes all major hardware, installation, start-up costs, labor, freight, diving and special equipment expenses. The above project cost does not include housing structure for the compressors, bringing electric power to the site, or the trenching of air lines. Assuming 150 days of operation at $0.08 per kilowatt-hour, the annual operational cost is estimated at $23,328.

Based on the high estimated project and annual operating costs, hypolimnetic aeration does not appear to be a cost-effective management alternative for Dallas Lake.

Hackenburg Lake

The anoxic volume of water for Hackenburg Lake was estimated at 1.18 million cubic meters and would require approximately 71 kilograms of oxygen per day (oxygen supply rate). Based on the lake morphology and the required oxygen supply rate, one aerator and one (3) horse powered air compressor would be needed. The estimated project cost is $51,275, which includes all major hardware, installation, start-up costs, labor, freight, diving and special equipment expenses. The above project cost does not include the housing structures for the compressor, bringing electric power to the site, or the trenching of air lines. Assuming 150 days of operation at $0.08 per kilowatt-hour, the annual operational cost is estimated at $562.

Based on the relatively low estimated project and annual operating costs, hypolimnetic aeration may be a viable management alternative for Hackenburg Lake. It should be noted that high concentrations of phosphorus in the bottom waters than in the surface waters indicate that internal phosphorus loadings from the lake sediments may be important.

Martin Lake

The anoxic volume of water for Martin Lake was estimated at 2.13 million cubic meters and would require approximately 128 kilograms of oxygen per day (oxygen supply rate). Based on the lake morphology and the required oxygen supply rate, one aerator and one (5) horse powered air compressor would be needed. The estimated project cost is $62,275, which includes all major hardware, installation, start-up costs, labor, freight, diving and special equipment expenses. The above project cost does not include housing structures for the compressor, bringing electric power to the site, or the trenching of air lines. Assuming 150 days of operation at $0.08 per kilowatt-hour, the annual operational cost is estimated at $1,037.

Based on the relatively low estimated project and annual operating costs, hypolimnetic aeration may be a viable management alternative for Martin Lake.

Messick Lake

The anoxic volume of water for Messick Lake was estimated at 7.91 million cubic meters and would require approximately 475 kilograms of oxygen per day (oxygen supply rate). Based on the lake morphology and the required oxygen supply rate, two aerators and one (20) horse powered air compressor would be needed. The estimated project cost is $117,125, which includes all major hardware, installation, start-up costs, labor, freight, diving and special equipment expenses. The above project cost does not include housing structures for the compressor, bringing electric power to the site, or the trenching of air lines. Assuming 150 days of operation at $0.08 per kilowatt-hour, the annual operational cost is estimated at $4,018.

Based on the relatively low estimated project and annual operating costs, hypolimnetic aeration may be a viable management alternative for Messick Lake. In Messick Lake, phosphorus concentrations were higher in the bottom waters than in the surface waters, thus indicating that internal phosphorus loadings from the lake sediments may be important.

Olin Lake

For Olin Lake, the dissolved oxygen in the hypolimnion never fell below 2 mg/L. In addition to high dissolved oxygen levels, Olin Lake recorded one of the lowest hypolimnetic phosphorus concentrations of all the ten lakes. Therefore, an in-lake aeration system was not considered a necessary restoration alternative for Olin Lake.

Oliver Lake

For Oliver Lake, the dissolved oxygen in the hypolimnion only fell below 1 mg/L at depths exceeding 88 feet (27 meters), therefore the majority of the hypolimnion was well oxygenated. In addition to high dissolved oxygen levels, Oliver Lake recorded one of the lowest hypolimnetic phosphorus concentrations of all the ten lakes. Therefore, an in-lake aeration system was not considered a necessary restoration alternative for Oliver Lake.

Westler Lake

The anoxic volume of water for Westler Lake was estimated at 7.97 million cubic meters and would require approximately 478 kilograms of oxygen per day (oxygen supply rate). Based on the lake morphology and the required oxygen supply rate, two aerators and one (20) horse powered air compressor would be needed. The estimated project cost is $117,125, which includes all major hardware, installation, start-up costs, labor, freight, diving and special equipment expenses. The above project cost does not include housing structures for the compressor, bringing electric power to the site, or the trenching of air lines. Assuming 150 days of operation at $0.08 per kilowatt-hour, the annual operational cost is estimated at $4,018.

Based on high sediment phosphorus concentrations, high hypolimnetic phosphorus concentrations, and relatively low estimated project and annual operating costs, hypolimnetic aeration may be a viable management alternative for Westler Lake.

<u>**Witmer Lake**</u>

The anoxic volume of water for Witmer Lake was estimated at 5.17 million cubic meters and would require approximately 3,103 kilograms of oxygen per day (oxygen supply rate). Based on the lake morphology and the required oxygen supply rate, three aerators and two (50) horse powered air compressors would be needed. The estimated project cost is $259,450, which includes all major hardware, installation, start-up costs, labor, freight, diving and special equipment expenses. The above project cost does not include housing structures for the compressors, bringing electric power to the site, or the trenching of air lines. Assuming 150 days of operation at $0.08 per kilowatt-hour, the annual operational cost is estimated at $18,749.

Based on the high project and annual operational costs, hypolimnetic aeration does not appear to be a cost-effective management alternative for Witmer Lake.

5.1.2 Dredging

The physical removal of lake sediments can be used to achieve one or more objectives, including macrophyte removal, lake deepening, and nutrient removal. The most obvious advantage of dredging is the immediate removal of virtually all plants from the lake bottom. Therefore, all of the nutrient compounds and organic matter which comprise the existing vegetative biomass are permanently removed from the lake system. The entire macrophyte mass would be eliminated, including the seeds and roots, thereby preventing a quick recurrence of nuisance growths.

Problems associated with in-lake dredging are the resuspension of sediments and nutrients, the disturbance of the benthic community, and the disturbance of both fishery nesting and refuge areas. During the dredging operation, sediments and nutrients are often resuspended, which may result in algal blooms, increased turbidity, and decreased dissolved oxygen concentrations. By removing in-lake sediments, many of the residing aquatic organisms will be physically removed or smothered by the settling sediments in areas adjacent to the actual operation. In addition to the benthic community, both fish nesting (breeding) areas and refuge areas for juvenile fishes may also be removed or silted in by sediment. However, the continued improvement of hydraulic dredging equipment and dredging methods have helped to minimize these adverse impacts.

Complete bathymetric surveys, which include sediment depth profiles, were beyond the scope of this study. Therefore, any volumes of sediment to be removed and their associated costs are only intended as "estimates". In-lake sediment dredging costs are highly variable and may range from $5 to $100 per cubic yard of sediment removed. In general, hydraulic dredging is more cost-effective than mechanical dredging. Typically costs for hydraulic dredging in-lake sediments are expensive and range from $21 to $25 per cubic yard of sediment removed. This cost includes engineering design work, construction, dredging, sediment disposal and permit preparation.

In contrast to contracting out in-lake sediment dredging, LaGrange County or South Central LaGrange County Water Quality Commission (SCLCWQC) may wish to establish its own non-profit sediment dredging program. For example, Washington Township established an in-lake sediment dredging program for Ediboro Lake, which is approximately 250 acres in size and is located in Erie County, Pennsylvania. This program was funded by private sources and state grant monies for a total project cost of $320,000. The total project cost included the purchase of all dredging equipment, equipment maintenance, sediment disposal, and operators' salaries (non-union employees). Over a two and one-half year period, approximately 50,000 cubic yards of sediment were removed at a cost of $6.40 per cubic yard. The sediment was pumped directly from the barge to two nearby abandoned gravel pits, which greatly increased the overall cost-effectiveness of this project.

For the ten LaGrange County lakes, dredging evaluations primarily focused on shallow channels and near shore areas, where navigation was severely impaired by excessive sediment deposits and dense aquatic plant growth. In some instances, rooted and unrooted submerged aquatic vegetation can grow in waters approaching ten feet in depth. For these areas, where only macrophytes impair navigation, in-lake sediment dredging was not considered because other alternatives, such as, benthic barriers or weed harvesting practices may be more cost effective.

In estimating the volume of lake sediments to be dredged, a minimum final depth of five feet was selected. For each lake, the final cost for hydraulic dredging was estimated by assuming an average cost of $23 per cubic yard of sediment removed. This average cost for sediment dredging was based upon projects that were similar to the ten Indiana lakes and includes engineering design work, construction, dredging and permit preparation. For each of the ten LaGrange County lakes, an estimate of sediment dredging volumes and associated costs are presented below.

For each of the ten LaGrange County lakes, recommended lake areas to be dredged were classified as candidate areas and high priority areas. Candidate areas, which include high priority areas, are all lake areas that have accumulated excessive amounts of sediment and adversely affect some lake users. Candidate areas include shallow man-made channels, which provide access to the lake from adjacent private lands. On the other hand, priority areas only include those shallow lake areas which adversely affect a large number of lake users.

Adams Lake

At Adams Lake, three sites were identified as possible candidates for in-lake sediment dredging. These sites were as follows: two channels located on the west shoreline of the lake, three channels located on the east shoreline of the lake, and the shallow area near the boat launch. For these three sites, it was estimated that 27,591 cubic yards of sediment could be removed at a total cost of $634,593.

Another option is to only spot dredge high priority areas in the lake. In spot dredging operations, smaller, more mobile equipment is often used instead of large dredging barges. For Adams Lake, the shallow area near the public boat launch area may be a candidate for spot dredging, thereby increasing public access to the lake. For the public boat launch area, approximately 1,333 cubic yards of sediment could be removed at a cost of $30,659.

Atwood Lake

At Atwood Lake, two sites were identified as possible candidates for in-lake sediment dredging. These sites were as follows: two channels and the shallow area located on the east shoreline of the lake. For these two sites, it was estimated that 39,839 cubic yards of sediment could be removed at a total cost of $916,297.

Based on the cost and the low number of individuals that would actually benefit from this project, lake-wide dredging does not appear to be a viable restoration alternative for Atwood Lake. The shallow eastern shoreline may be important to the overall management of the lake's fishery and should be left untouched. Most shallow weedy areas provide good spawning areas for warm-water fish in the spring months and nurseries for fry and juvenile fish.

Dallas Lake

At Dallas Lake, three sites were identified as possible candidates for in-lake sediment dredging. These sites were as follows: two channels located on the west shoreline of the lake, two channels located on the east shoreline of the lake, and the shallow shoreline area near the eastern channels. For these three sites, it was estimated that 33,853 cubic yards of sediment could be removed at a total cost of $778,619.

Based on the high cost and the wide variety of lake uses that currently exist at the lake, in-lake sediment dredging does not appear to be a viable restoration alternative for Dallas Lake.

Hackenburg Lake

At Hackenburg Lake, two sites were identified as possible candidates for in-lake sediment dredging. These sites were as follows: five channels and the shallow shoreline area located on the south bank of the lake's outlet, and a shallow area located on the western shoreline. For these two sites, it was estimated that 13,041 cubic yards of sediment could be removed at a total cost of $299,943.

Based on the cost and the number of lakeside property owners that would benefit from this project, lake-wide dredging may be a viable option as a restoration alternative for Hackenburg Lake. If the above areas are dredged, the northern shallow shoreline area, which contains a variety of macrophytes, should be left in its natural condition. Generally, most shallow weedy littoral zones provide good spawning areas for warm-water fish in the spring and nurseries for fry and juvenile fish. Therefore, the northern shoreline may be extremely important to the overall fishery in Hackenburg lake.

Martin Lake

In Martin Lake, no sites were identified as potential candidates for in-lake sediment dredging. In the lake, submerged aquatic vegetation was observed in waters approaching ten feet in depth. In these areas and other areas, where only macrophytes impair navigation, the use of benthic barriers or weed harvesting equipment may be more cost effective.

In Martin Lake, many of the macrophytes appear to be quite beneficial. Many of the weeds in shallow waters provide excellent spawning areas for adult warm-water fish and nurseries for both fry and juvenile fish. In addition to fisheries enhancement, the macrophytes along the eastern shoreline serve as "biological filters", thereby reducing the sediment and nutrient loadings to the lake from two inflowing tributaries.

Messick Lake

At Messick Lake, three sites were identified as possible candidates for in-lake sediment dredging. These sites were as follows: the shallow shoreline area located on the east bank of the northern inlet, the northern inlet channel, and two channel extending from the northern inlet. To provide a minimum water depth of five feet at the above areas, approximately 10,003 cubic yards of sediment would have to be removed at an estimated cost of $230,069.

Based on the cost and the number of individuals that may benefit, in-lake dredging may be a viable restoration alternative.

Olin Lake

In light of the fact that Olin Lake is undeveloped and considered a natural preserve area, no in-lake dredging should be implemented. In addition to the lake, the channels extending from Olin Lake to Martin and Oliver Lakes should not dredged. This is due to the fact that both of channels also lie within the boundaries of the Olin Natural Preserve.

Oliver Lake

At Oliver Lake, two sites were identified as possible candidates for in-lake sediment dredging. These sites are as follows: five channels located at the north northwestern shoreline (includes the Dove Creek inlet and the public boat launch) and the channel between Basin Lake and Oliver Lake (near the outlet of Oliver Lake). To provide a minimum water depth of five feet in the above channels, approximately 18,502 cubic yards of sediment would have to be removed at an estimated cost of $425,546.

Another option is to only dredge high priority areas in the lake, such as, the shallow channel at the public boat launch area and the inlet of Dove Creek. By dredging sediments near the public boat launch channel, public access to the lake will be enhanced. To provide a minimum water depth of five feet in the above channels, approximately 5,052 cubic yards of sediment must be removed at an estimated cost of $116,196.

Westler Lake

At Westler Lake, three sites were identified as possible candidates for in-lake sediment dredging. These sites were as follows: the shallow shoreline area at the lake's outlet, the channel between Westler and Witmer Lakes, and three channels located on the lake's northern shoreline. To provide a minimum water depth of five feet at the above areas, approximately 16,863 cubic yards of sediment would have to be removed at an estimated cost of $387,849.

Based on the above cost and the wide-variety of lake uses that currently exist at the lake, dredging does not appear to be a viable restoration alternative for Westler Lake.

Witmer Lake

At Witmer Lake, two sites were identified as possible candidates for in-lake sediment dredging. These sites were as follows: eight channels located along the lake's northern shoreline and two channels located along the eastern shoreline. To provide a minimum water depth of five feet at the above areas, approximately 43,849 cubic yards of sediment would have to be removed at an estimated cost of $1,008,527.

Based on the cost and the low number of lakeside property owners that would benefit from this project, lake-wide dredging does not appear to be a viable restoration alternative for Witmer Lake.

It should be noted that the littoral zone along the northeastern shoreline area should not be disturbed. This shallow weedy area contains a variety of macrophytes and is the only natural shoreline in Witmer Lake. Generally, most shallow weedy littoral zones provide good spawning areas for warm-water fish in the spring and nurseries for fry and juvenile fish. Therefore, the northeastern shoreline may be extremely important to the overall fishery in Witmer Lake.

5.1.3 Macrophyte Harvesting

Aquatic weed harvesting is used for two lake restoration purposes: (1) to physically remove nuisance vegetation, and (2) to remove nutrients and organic matter from the lake ecosystem. Harvesting is a direct way to accomplish the first goal with minimal negative impacts. The actual harvesting does not interfere with the use of a lake, improves recreational usage and does not introduce foreign substances (algicides or herbicides) to the ecosystem. Weed harvesting is used primarily to restore the recreational uses of a lake. However, the technique presents a maintenance problem since the equipment seldom removes the entire plant. Most lakes usually require two to three cuttings per year in order to maintain the weeds at a non-nuisance level. The frequency of cutting, however, may be reduced after several years of harvesting.

The advantages of weed harvesting versus chemical application were evaluated for a small lake in Ohio (Conyers and Cooke, 1982). It was concluded that harvesting is much more effective than the recommended doses of Cutrine-Plus and Diquat in controlling the biomass, and harvesting would be less costly over a two-year period than chemical treatment for the same period.

In addition to removing nuisance plant growth, harvesting can result in water quality improvements. Removing intact plants reduces the oxygen demand associated with decaying plants and improves fish habitat. Since up to 50 percent of dead plant tissue deposited on a lake bottom does not decompose, sediment and detrital accumulation rates would decrease with harvesting. The benefit in harvesting macrophytes to remove nutrients is less certain. When possible, plants absorb nutrients in excess of their needs. As much as 0.05 to 0.4 grams per square meter of phosphorus per year can be removed from a lake by mechanical harvesting (Burton, et al., 1979). In order to have a net effect, removal of phosphorus by harvesting would have to exceed the annual phosphorus accumulation rate. Phosphorus removal is affected by the type of harvesting operation, the amount of phosphorus stored in the sediments and taken up by vegetation, and whether nutrient inputs are controlled. Net nutrient removal is likely only in limited instances where nutrient inputs are reduced to low levels. It would most likely take years to deplete the supply of phosphorus stored in the upper layers of the sediment. In the ten LaGrange County lakes, plant removal would have no relative effect on in-lake phosphorus concentrations.

Compared to other restoration techniques, the cost of aquatic weed harvesting is moderate. The size and type of harvesting operation determines the type of machinery that should be used and the cost-effectiveness of purchasing equipment versus contracting a harvester. In general, those harvesters that cut the macrophytes and immediately remove them by means of a conveyor are most effective.

The potential negative environmental impacts of harvesting include:

1. A change in the dominant plant species,
2. A change in the composition of benthic and aquatic organisms,
3. Short-term suspension of sediments and detritus,
4. Dissolved oxygen depletion due to plant decomposition,
5. Nutrient release to the water column from decaying plants and ruptured stems, and
6. An increase in algae populations.

The extent and likelihood of these effects depend in part on the completeness of macrophyte removal and on the magnitude of sediment release of nutrients and nonpoint sources of nutrients.

There are several ways to establish a weed harvesting program. They are 1) purchase and run your own harvester, 2) share a harvester with other lakes or establish a county-wide harvesting program, or 3) contract the harvesting to an outside service. Purchasing and running your own harvester is initially the most expensive way to establish a harvesting program. Over the long-term, the initial expense will be offset by the cost of contracting out, but annual operational and maintenance costs will continue. The cost to an individual lake association can be reduced by sharing ownership among several lakes or by establishing a county-wide macrophyte harvesting program.

The cost for equipment depends on the size of the harvester and ranges between $50,000 and $120,000 for the mechanical weed harvester, shore conveyor and trailer. Weed harvesters can cut approximately one acre of weeds in 4 to 8 hours and typically cost about $200 per acre to operate not including the disposal of cut vegetation (New York Department of Environmental Conservation, 1990). The actual time and operational cost will be highly dependent on the harvester unit selected and the density of the macrophytes. The harvester should be able to cut a swath ranging from six to ten feet in width and to a depth of six to eight feet. The use of mechanical harvesters is generally limited to lake depths greater than 2.0 feet and beyond docks due to poor maneuverability. It should be noted the above cost does not include weed disposal.

Instead of a lake association or a county purchasing its own weed harvesting equipment, a lake association may choose to contract out its weed harvesting duties. Typically, contractor rates for weed harvesting are quite variable and greatly depend on the geographic location of the lake and local market prices. Based on conversations with local subcontractors in the ten lakes region, weed harvesting fees are typically $75 per hour, therefore weed harvesting in open waters and channels will cost approximately $225 to $375 per acre, respectively. The above costs do not include hauling fees to the weed disposal site.

After harvesting, the weeds are usually unloaded from the harvester to trucks via shore conveyor units. Prior to the commencement of any weed harvesting activities, several weed disposal sites should be identified. Aquatic weeds compost well, thereby producing a good mulching material. In many instances, the agricultural community will generally accept harvested weeds. In any of the above approaches to weed harvesting, it is important to find a close disposal site, thereby reducing hauling costs for weed disposal.

All Ten Lakes

For each of the ten LaGrange County lakes, weed harvesting should be limited to waters where navigation is severely impaired by excessive weed growth and currently receives herbicidal treatments. Since the ten lakes receive relatively high nutrient loadings from their surrounding watersheds, weed harvesting is not expected to be highly effective in removing in-lake nutrients. In areas not impairing navigation, stands of macrophytes should not be harvested, thereby providing nurseries for juvenile fish, cover and spawning areas for adult fish, and food and cover for wildlife.

In many of the ten LaGrange County lakes, weeds are confined to channels and shallow waters along the shoreline. This is especially true for Adams, Dallas, Messick, Olin, Oliver, Westler and Witmer Lakes. For these lakes, lake-wide weed harvesting does not appear to be a viable restoration alternative. In Witmer Lake, macrophyte harvesting should not be allowed along the northern shorelines area. Stands of macrophytes along this shoreline appear to be quite beneficial to the lake's overall fishery.

In Martin Lake, many of the weeds are beneficial to the lake's fishery and in reducing nutrient and sediment loadings from inflowing tributaries. Therefore, lake-wide weed harvesting in Martin Lake is not recommended. In Martin Lake, many of the macrophytes appear to be quite beneficial. Many of the macrophyte stands provide excellent spawning areas for adult warm-water fish and nurseries for both fry and juvenile fish. Also, the macrophytes along the eastern shoreline serve as "biological filters", thereby reducing sediment and nutrient loads to the lake from two inflowing tributaries.

Of the ten LaGrange County lakes, only Atwood Lake and Hackenburg Lake appear to be candidates for lake-wide weed harvesting. In Atwood Lake, three possible weed harvesting sites are as follows: the western shoreline, the southern shoreline near the campground, and the eastern shoreline near the lake's outlet. In Hackenburg Lake, only the shorelines on both sides of the lake's outlet appear to be suitable for weed harvesting. In these lakes, the following areas should not be harvested: the eastern shoreline at Atwood Lake and the northern shoreline at Hackenburg Lakes. These shallow weedy areas appear to be very important to the overall fishery in Atwood and Hackenburg Lakes.

As opposed to lake-wide harvesting, localized weed harvesting may be more appropriate for weed choked channels in the above lakes. In localized weed harvesting, nuisance weed growth in the center of the channel can be removed by using smaller harvesting equipment. For channel and lakeside property owners who have poor access to the weed free waters, benthic barriers may be installed in the vicinity of docks.

5.1.4 Water Level Controls

The intent of water level control is to manipulate the aquatic habitat and create conditions unfavorable for aquatic plant growth. One approach is to raise the water surface elevation. A higher water level deepens a lake, increases the lake volume, and allows less light to reach the bottom of the lake where plants grow. This approach, however, does not address the causes of excessive plant growth-sediment accumulations and high nutrient concentrations. In addition, this method has limited practical applications. For any of the ten lakes, raising the water surface elevation would require modifications to the existing dam and spillway structures. In addition to these structures, raising the water elevation would likely result in the destruction of both fish and wildlife habitat at the lakes' edge, and the flooding of adjacent open space which includes private property.

Water level drawdown is a second approach and has been used for at least the short-term control (one to two years) of susceptible nuisance macrophyte species. The object of water level drawdown is to retard aquatic macrophyte growth by destroying seeds and vegetative reproductive structures through drying or freezing conditions, or by altering their substrate through sediment dewatering. Water level drawdown may also compact the exposed sediments to a certain degree, thereby reducing the need for dredging.

Drawdown can be implemented at a relatively low cost providing a lake has an outlet structure which can allow a water lowering of at least five feet. For the ten Indiana lakes, no sufficient outlet structures currently exist. For any of the ten lakes, outlet channels would have to be deepened and control structures installed. Secondly by drawing down a particular lake, other lakes of the chain system may also be affected.

All Ten Lakes

Based on Chapter 350 of the Indiana Code (IC) 13-2-18, legal levels for many natural lakes in the state of Indiana have been established by the Indiana Department of Natural Resources at the request of the local courts. With regard to Chapter 350, water level control as an in-lake management alternative is prohibited by law in the state of Indiana without court permission.

5.1.5 Chemical Controls

Chemical treatment has been used extensively in lakes to control the growth of aquatic vegetation. Excessive macrophyte and algae growth, can generally be controlled with herbicides and algicides if the proper chemical or combinations of chemicals are selected and properly applied. Over a short period of time chemicals are effective in killing vegetation and restoring the recreational use of a lake, thus their widespread use. Over a long period of time, chemical controls are unsuccessful because they treat only the symptoms of eutrophication, not the causes. As can be observed in many of the ten lakes, nutrients released from decaying plants, which were killed with chemicals, may often cause the formation of floating mats of algae.

Excessive growth of aquatic plants and algae could also be reduced through control of nutrients. The best method is to limit the nutrients entering the lake by controlling them at their source with watershed management practices such as land use controls, septic system maintenance, and erosion control. In-lake nutrient controls such as chemical nutrient inactivation can also be effective.

Algicides

Copper sulfate and copper compounds are the most commonly used general algicide. The solubility of copper sulfate and subsequently its effectiveness is influenced by pH, alkalinity, and temperature. Copper sulfate is most effective in soft, mildly acidic waters. If added in excessive amounts, copper sulfate can be toxic to fish and other forms of aquatic life. It can also accumulate in the lake sediments. One of the problems with the use of copper sulfate is its specificity for only certain algae. It is successful in causing a change in the dominant species of algae in a body of water. There are times when the algae replacing the original problem species cause problems of their own, and these latter algae are not controlled by usual treatments of copper sulfate. Copper sulfate costs ranged from $5 to $25 per acre-foot in 1990 (NYDEC 1990). This cost does not include application fees. Assuming a 5 percent inflation rate, copper sulfate costs are estimated at $5.50 to $27.50 per acre-foot in 1992.

Herbicides

Chemical treatment provides only temporary relief from chronic aquatic weed problems. In many instances, application is required at least twice per year. Therefore, the costs for chemical treatment are relatively high. An experimental study on East Twin Lake in Ohio concluded that weed harvesting was far more cost-effective than chemical treatment (Conyers and Cooke, 1982). The cost for one application of herbicide ranges from $140 to $310 per acre in 1984 (EPA, 1990). The above range of costs include application fees. Assuming a 5 percent inflation rate, this cost is estimated at $210 to $460 in 1992.

Although the method of chemical control has been extensively used, there has been relatively little documentation regarding environmental impacts. Although refuted by chemical manufacturers, there are still questions regarding the toxicity of certain chemicals to fish and other food chain organisms.

Copper sulfate has been shown to be toxic to fish under certain circumstances. Unlike compounds containing heavy metals, most of the organic chemicals do not appear to accumulate in lake systems.

Benefits to the use of herbicides include:

1. Effective short-term management to rapidly reduce aquatic weeds for periods of weeks to months.

2. Application of herbicides is less time consuming than other weed control techniques.

Drawbacks to the use of herbicides include:

1. Vegetation is not removed from lake.

2. Plants die, decompose and release nutrients in the lake.

3. Dissolved oxygen concentrations are depleted by microbial decomposition. This may induce the release of nutrients from the sediments.

4. Algal blooms often occur as a result of increased nutrient levels.

5. Herbicides can be toxic to non-target species.

6. Some plant species may be tolerant to the herbicides.

7. Some herbicides are suspected to be mutagenic and carcinogenic.

8. The waiting period (10 days or more in most cases) following application of many herbicides interferes with recreational lake uses.

9. Unsightly conditions are often created.

All Ten Lakes

For all of the ten LaGrange County lakes, the use of chemical algicides and herbicides should be minimized and included only as part of an overall integrated approach to managing macrophytes, such as spot dredging, benthic barriers, and weed harvesting.

5.1.6 Biological Controls

Biomanipulation or Food Web Manipulation (Shapiro, 1978) has been suggested as one method of controlling algal blooms in lakes. Theoretically, balancing phytoplankton (microscopic plants), zooplankton (microscopic animals), and fish populations will eliminate nuisance algal blooms. Biomanipulation usually involves reducing planktivorous fish (zooplankton-eating) and increasing piscivorous fish (fish-eating) populations. By restructuring the aquatic food web, the number of larger zooplankton species would increase, thereby reducing the algal populations.

To shift the fish population from planktivorous to piscivorous, the following techniques may be employed: water level drawdown, electroshocking, winter kill, intensive seining, piscicides, or predatory fish stockings. Water level drawdown will reduce planktivorous by trapping them in littoral zone and shallow pools, and exposing fish eggs to the atmosphere. Electroshocking uses a electrical current to temporarily stunned the fish, thereby allowing planktivorous fish to be selectively removed from the lake. Winter kill involves spreading sand over a frozen lake surface. By reducing the light to penetrate the ice, winter algae population will decrease, resulting in less food for planktivorous fish. Seining requires the use of nets to trap fish. By selecting the appropriate net mesh size, certain fish can be removed from the lake. Piscicides (fish-killing poisons) may be applied to reduce the numbers of undesirable fish species. Lastly, the introduction of predator fish species through stocking programs. This last technique is often employed in conjunction with one or more of the above techniques and is more often known as "fisheries enhancement" rather than "algae control" (New York State Department of Environmental Conservation, 1990).

In general, biomanipulation is not well understood because only a limited number of case studies have sufficiently documented its successes. In general, lakes are very complex ecosystems with numerous biological, chemical and physical interactions. By varying one or several biological components within a lake's food web, the effects may be dramatic at a given time, but how this change affects the lake in the future is poorly understood.

In contrast to the introduction of predatory fish as discussed above, the use of herbivorous fish, such as grass carp (*Ctenopharyngodon idella*), has also been suggested as a lake management option. Grass carp prefer tender plant species, and would control wipe out the desirable species such as tapegrass (*Vallesnaria*) as well as the less desirable species, such as coontail (*Ceratophyllum*) and milfoil (*Myriophyllum*). Their ability to control waterlilies (*Nympheae* and *Nuphar*), however, is doubtful.

While triploid grass carp can not reproduce, they are still considered an exotic species by many states and their introduction is prohibited. Grass carp can not be brought into Indiana or released into public or private waters without a permit issued by the Director of the Division of Fish and Wildlife. The director may issue such permits for scientific or educational purposes only.

There are a number of negative effects associated with the introduction of grass carp. Grass carp may destroy desirable macrophyte species. Grazing by grass carp may reduce macrophyte biomass, but does not remove the nutrients from the lake. This may lead to increased eutrophication of a lake, with lower dissolved oxygen concentrations and increased algal blooms.

<u>All Ten Lakes</u>

For the ten LaGrange County lakes, phytoplankton counts were fairly low, especially for Olin and Oliver Lakes. In eight of the ten lakes (Adams, Atwood, Dallas, Hackenburg, Martin, Messick, Westler and Witmer), the phytoplankton communities were dominated by various species of blue-green algae, such as, *Microcystis*, *Aphanizomenon*, *Anabaena* and *Lyngbya*. In Olin and Oliver Lakes, the phytoplankton assemblage was primarily comprised of diatoms, namely the species *Fragilaria*. In general, diatoms are preferably grazed over blue-green algae by zooplankton. Most species of blue-green algae form large colonies, which may significantly reduce their availability to filter feeding zooplankton.

For the ten LaGrange County lakes, biomanipulation does not appear to be a viable in-lake management technique. As stated above, the phytoplankton communities in Adams, Atwood, Dallas, Hackenburg, Martin, Messick, Westler and Witmer Lakes were dominated by blue-green algae, which are not readily eaten by zooplankton. In Olin and Oliver Lakes, diatoms dominated the phytoplankton assemblage. Though readily consumed by zooplankton, these algae were only present in very low numbers.

In addition to biomanipulation techniques, the use of triploid grass carp to control macrophytes is not recommended for any of the ten Indiana lakes. This is primarily due to regulatory restraints imposed by the Indiana Department of Natural Resources and the potential for negative impacts on water quality.

5.1.7 Physical Barriers

Physical sediment covering is another method which has been used to control aquatic and sediment nutrient release. Researchers have experimented with various cover materials including sand, clay, synthetic sheeting and fly ash.

The primary advantages of sand is its lower material and application costs. However, sand has not been shown to provide either an effective physical or chemical barrier when used as a solitary treatment approach. Both macrophytes and nutrients are usually able to break through sand coverings. One apparently successful application of sand occurred in a lake where the nutrient-rich sediments were first excavated from the lake bottom.

A more promising candidate for a natural sealant might be clay. Although a full scale treatment with clay has not been reported, laboratory experiments indicated that a two inch layer of kalinite was effective in retarding phosphorus release for up to 140 days. However, the seal was eventually disrupted by gas formation in the sediments. In addition, it might be necessary to add a precipitant such as alum to remove colloidal clay particles from the water column. Also, the effect of rooted macrophytes on a clay layer has not been adequately tested. Overall, the use of clay or sand are not considered to be applicable to the ten Indiana lakes since these methods involve decreasing the depth of the lake.

The use of fly ash (a waste product from coal combustion) to control phosphorus release from sediments has also been tested. However, besides being susceptible to plants and gases in the same manner as sand and clay, the use of fly ash may cause adverse effects such as high pH, dissolved oxygen depletion, biological reduction of sulfate to sulfide, heavy metal accumulation and toxicity, and the physical clogging and crushing of organisms.

One of the more successful approaches for covering lake sediments to control aquatic plants has involved the use of synthetic sheeting (benthic barriers). Sheeting can be installed by first lowering the water level, installing cover on ice surface and allowing it to sink during ice-out, or by wading out and installing it directly under water.

There have been several problems with the use of this material, including:

1. holes have to be placed in the sheeting to avoid the formation of gas pockets.

2. The sheeting was easily dislodged by currents.

3. The sand which is often used as an anchor can become enriched with new sediments and tends to again support weed growth after two to three years.

4. Polyethylene degrades rapidly in sunlight.

5. The sheeting may have severe impacts on the benthic community.

The most effective benthic covers are gas permeable screens, which are constructed of fiberglass, polypropylene, or nylon as opposed to those gas impermeable covers constructed of polyethylene or synthetic rubber materials. For the above screen materials, both fiberglass and polypropylene materials are generally the easiest to install and the most effective in controlling macrophytic growth (EPA, 1990).

The installation of benthic covers over large areas has only been successful demonstrated for several years. Once in place, sediments may accumulated on the barrier, thereby allow plant fragments to re-establish. Therefore, screens must removed and periodically cleaned, possibly every 2 to 3 years. For localized control, such as around docks, benthic barriers are routinely installed in early spring and removed in the fall. While this introduces a winter storage problem, it prevents the re-establishment of macrophytes.

All Ten Lakes

With the exception of Olin Lake, which is a natural preserve area, benthic barriers may be applied as part of an integrated aquatic plant management plan for each of the Indiana lakes. Where plant growth is dense, benthic barriers could be installed from individual docks to the edge of the littoral zone (the region extending from the lake's shoreline to open water), thereby increasing boat access to the open water and reducing the use of aquatic herbicides. Of the wide-variety of materials on the market, fiberglass or polypropylene materials should be used over other barriers because these materials are gas permeable and are easier to install.

Assuming an individual dock requires 400 square feet (20 by 20 feet) of lake bottom to be covered, polypropylene and fiberglass netting would cost approximately $40 and $120, respectively. The above costs do not include shipping and installation, and any additional materials, such as benthic anchors.

5.1.8 Nutrient Inactivation

Since phosphorus-rich sediments will release phosphorus in the water column under low oxygen conditions, water quality problems can continue in a lake long after watershed controls are implemented. By applying aluminum salts (commonly refer to as alum) to lake sediments, a chemical barrier is established which can provide continuous control of phosphorus. Nutrient inactivation usually consists of adding aluminum salts (aluminum sulfate and/or sodium aluminate) to produce an aluminum hydroxide floc which forms a chemical bond with phosphorus. Under the appropriate lake conditions, this method has been known to reduce internal phosphorus loadings for periods of 5 to 15 or more years. Alum treatments are most effective in deep lakes with a surface area greater than 50 acres in size and a low flushing rate, and where watershed inputs of phosphorus have been minimized.

Connor and Martin (1989) and Cooke, et al. (1986) provide an excellent summary of the effects and costs of using aluminum salts (alum) to inactivate sediment phosphorus. Assuming that watershed phosphorus loading has been minimized, this management technique can provide long-term improvements in water quality with minimal negative environmental impacts. Based on the treatment costs for six New England lakes, the average cost was approximately $1,372 per hectare at a mean aluminum dosage of 28 grams of aluminum per cubic meter (Connor and Martin, 1989). In recent years, the trend has been towards using higher application dosages ranging from 40 to 45 grams of aluminum per cubic meter. Due to advancements in application technologies, alum treatment costs in the mid-1980's have been further reduced to $1,306 per hectare at a dosage of 40-45 grams of aluminum per cubic meter. At an annual inflation rate of five percent, this would be equivalent to $1,838 per hectare in 1992.

The actual aluminum dosage is lake specific and largely depends on the results from jar tests, which are performed in the laboratory. For the ten Indiana lakes study, jar tests were beyond the scope of this project. Therefore for each of the ten Indiana lakes, the costs for hypolimnetic alum treatments are only intended as "estimated" values and are based on the above cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter.

For in-lake alum treatment to be cost-effective, a lake should have a long hydraulic residence time (generally greater than 0.5 years), high sediment phosphorus concentrations, high hypolimnetic phosphorus concentrations, high summer phytoplankton levels, and low total suspended and phosphorus loadings from its surrounding watershed. In the following paragraphs, the estimated cost for alum treatment for each lake are discussed.

Adams Lake

Adams Lake has a hypolimnetic area of approximately 164 acres (66 hectares). Assuming an average alum cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter, the estimated cost to treat Adams Lake with alum is $121,308.

Based on the criterion listed in the introduction, Adams Lake is a possible candidate for alum treatment after the proposed wastewater treatment facility is on line. This facility is expected to reduce the total phosphorus loading by approximately 8 percent. In-lake management alternatives should only be considered if lake water quality does not improve through the implementation of this wastewater treatment facility, watershed best management practices and agricultural best management practices.

Atwood Lake

Atwood Lake has a hypolimnetic area of approximately 41 acres (16 hectares). Assuming an average alum cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter, the estimated cost to treat Atwood Lake with alum is $29,408.

Based on the criterion listed in the introduction, in-lake alum treatment may be a viable management option for Atwood Lake. In-lake management alternatives should only be considered if lake water quality does not improve through the implementation of both watershed and agricultural best management practices.

Dallas Lake

Dallas Lake has a hypolimnetic area of approximately 158 acres (64 hectares). Assuming an average alum cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter, the estimated cost to treat Dallas Lake with alum is $117,632.

Based on low sediment and the hypolimnetic phosphorus concentrations and high phosphorus loadings from the lake's watershed, in-lake alum treatment does not appear to be a viable lake management option for Dallas Lake.

Hackenburg Lake

Hackenburg Lake has a hypolimnetic area of approximately 14 acres (6 hectares). Assuming an average alum cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter, the estimated cost to treat Hackenburg Lake with alum is $11,028.

Based on low sediment phosphorus concentrations, a very short hydraulic residence time, and high phosphorus loadings from the lake's watershed, in-lake alum treatment does not appear to be a viable lake management option for Hackenburg Lake.

Martin Lake

Martin Lake has a hypolimnetic area of approximately 15 acres (6 hectares). Assuming an average alum cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter, the estimated cost to treat Martin Lake with alum is $11,028.

Based on the criterion listed in the introduction, in-lake alum treatment may be a viable management option for Martin Lake. In-lake management alternatives should only be considered if lake water quality does not improve through the implementation of both watershed and agricultural best management practices.

Messick Lake

Messick Lake has a hypolimnetic area of approximately 40 acres (16 hectares). Assuming an average alum cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter, the estimated cost to treat Messick Lake with alum is $29,408.

Based on low sediment phosphorus concentrations, a short hydraulic residence time, and high phosphorus loadings from the lake's watershed, in-lake alum treatment does not appear to be a viable management option for Messick Lake.

Olin Lake

In Olin Lake, the dissolved oxygen levels in the hypolimnion never fell below 2 mg/L. Under aerobic conditions, orthophosphate combines with iron to form ferric phosphates, which eventually settle from the water column. Olin Lake had one of the lowest phosphorus concentrations for bottom waters. Therefore based on low phosphorus levels and aerobic conditions in the bottom waters, in-lake alum treatment is not considered a viable management option for Olin Lake.

Oliver Lake

In Oliver Lake, the dissolved oxygen levels in the hypolimnion fell below 1 mg/L only at depths exceeding 27 meters. Therefore, the majority of the hypolimnion in Oliver Lake was classified as aerobic. Under aerobic conditions, orthophosphate combines with iron to form ferric phosphates, which eventually settle out of the water column. Oliver Lake had one of the lowest hypolimnetic phosphorus concentrations. Therefore, based on low phosphorus levels and aerobic conditions in the bottom waters, in-lake alum treatment is not considered a viable management option for Oliver Lake.

Westler Lake

Westler Lake has a hypolimnetic area of approximately 62 acres (25 hectares). Assuming an average alum cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter, the estimated cost to treat Westler Lake with alum is $45,950.

Even though phosphorus levels in the lake's sediments and the hypolimnion were high, the hydraulic residence time is very low, therefore in-lake alum treatment does not appear to be a viable management option for Westler Lake.

Witmer Lake

Witmer Lake has a hypolimnetic area of approximately 174 acres (70 hectares). Assuming an average alum cost of $1,838 per hectare at a dosage of 40-45 grams of aluminum per cubic meter, the estimated cost to treat Witmer Lake with alum is $128,660.

Based on high sediment phosphorus concentrations, high hypolimnetic phosphorus levels, and a relatively high hydraulic residence time, in-lake alum treatment may be a viable management option for Witmer Lake only after the phosphorus loading from the lake's watershed is significantly reduced. In-lake management alternatives should only be considered if lake water quality does not improve through the implementation of both watershed and agricultural best management practices. It should be noted that Witmer Lake had the highest estimated phosphorus loadings for all the lakes in this study.

5.1.9 Dilution/Flushing

Dilution and flushing can improve water quality in eutrophic lakes by diluting the amount of phosphorus in the lake while increasing the flushing of algae from the lake. This technique works best in small eutrophic lakes that have low flushing rates (i.e. large lake surface area to watershed area) and is most cost effective when a large quantity of low-nutrient water is available. In most cases, the water supply for dilution and flushing is obtained by diversion of water from a nearby river, although wells may also be used. Some potential problems associated with the dilution and flushing technique are the degradation of the water quality in the lake itself and for downgradient watercourses. If the dilution water contains higher nutrient concentrations than existing concentrations in the lake and the algal growth rate exceeds the lake's flushing rate, the algae population in the lake may actually increase. Secondly by increasing the flushing rate of a lake, the water quality of the downstream watercourse may be degraded due to increased nutrient (which includes washed out algal cells) loadings.

All Ten Lakes

Based on trophic indices (Carlson's Trophic State Index and the Indiana Department of Environmental Management Eutrophic Index) which were calculated from water quality data as part of this study, eight of the ten lake systems (Adams, Atwood, Dallas, Hackenburg, Martin, Messick, Olin and Oliver Lakes) are classified as either oligotrophic or mesotrophic. Since the degree of eutrophy for these lakes is low to moderate, the use of the dilution and flushing technique is not applicable. If the dilution and flushing technique was employed in the above lakes, it is expected that the water quality would not significantly improve.

According to the above indices, only Westler and Witmer Lakes may be classified as eutrophic systems. By using the Dillon and Rigler model (1975), water quality changes due to increased flushing rates were analyzed for both Westler and Witmer Lakes. Based on the modeling results, it has been estimated that if the flushing rates for Westler and Witmer Lakes were doubled, the water quality for both lakes would not improve to a mesotrophic condition. As defined by Vollenweider (1977), an in-lake annual mean phosphorus concentration below 0.02 mg/L represents mesotrophic conditions. For Westler and Witmer Lakes, the lack of improvement in water quality is attributed to high pollutant loadings from nonpoint sources within their respective watersheds.

For the dilution and flushing to be cost-effective, a nearby, high quality surface water source is required. In the ten lakes region, the only suitable dilution waters are groundwater sources. For the volumes of groundwater needed by Westler and Witmer Lakes, the implementation of this technique would be cost prohibitive. Secondly since the ten LaGrange County lakes are interconnected via channels, there is the potential for degrading the water quality in downstream lakes by increasing their nutrient loadings from nutrient flushed from Westler and Witmer Lakes.

Therefore, based the low degree of eutrophy for eight of the lakes, the large volumes of dilution water required by Westler and Witmer Lakes, the lack of high quality surface waters to be used as dilution waters, and the potential degradation of downstream water quality, the dilution and flushing technique is not considered a viable in-lake restoration technique for any of the ten LaGrange County lakes.

5.2 Watershed Management Alternatives: Agricultural Best Management Practices

Nonpoint source pollution from agricultural runoff is a significant source of nutrient (phosphorus and nitrogen) and sediment loadings to the ten Indiana lakes. Based on the pollutant budgets developed in Section 5.0, agricultural land uses (row crop, feedlots, and pasture) contribute over 70 percent of the phosphorus and 95 percent of the suspended solid loadings for each of the ten Indiana lakes.

To reduce pollutant loadings from agricultural land uses, a number of agricultural best management practices (BMP's), such as conservation tillage, cover cropping, critical area planting, terraces, farmland management, fencing, agricultural waste storage structures, filter strips, grassed waterways, and impoundment ponds can be implemented in each of the ten Indiana lake watersheds. These agricultural BMP's are discussed in detail below.

Stream monitoring data along with the results of the AGNPS (Agricultural Nonpoint Source) modeling results in Appendix G should be used to identify high priority areas within the ten LaGrange County lakes. Once identified, agricultural BMP's can be implemented in these areas.

5.2.1 Conservation Tillage

Conservation tillage applies to crop tillage methods used to control the amount of erosion from crop fields. It is accomplished by leaving a certain percentage of the crop residue on the field at all times. Stormwater runoff can be reduced by retaining water on the fields and infiltration can be increased due to slower runoff velocities.

The most common conservation tillage practice is no-tillage or zero tillage. No-till farming involves soil preparation and planting that are accomplished in one operation with specialized farm equipment. This results in limited soil disturbance and leaves most crop residues on the soil surface. Planting is normally done in narrow slots opened by a fluted coulter or double-disk opener. Soil infiltration rates of the area are increased by maintaining a plant canopy or a mulch of plant residues on the surface for the entire year. However, soil compaction and reduction of evaporation from the surface due to the residues may lead to increases in runoff.

Other conservation tillage practices such as ridge planting, strip tillage, and plow planting are less common than no-tillage. Typically these methods require specialized soil and cropping conditions to be practical. Some of the conservation tillage methods may also decrease runoff volume by allowing significant amounts of runoff to infiltrate into the soil. The infiltration capacity is dependent on the amount of soil compaction in the undisturbed areas of the field and the amount of crop residues that are left exposed. High soil compaction inhibits infiltration whereas exposed crop residues absorb the water and retain it on site until it evaporates.

Additional benefits of conservation tillage include less labor per acre, lower equipment costs, and reduced fuel costs. Disadvantages of conservation tillage include increased use of herbicides, soil compaction, increased management requirements, and lower soil temperatures in spring caused by heavy mulch residue. Concentrations of nitrate in runoff water from conservation tilled fields are typically higher than concentrations from conventionally tilled fields. This is not necessarily a disadvantage since less runoff occurs from conservation tilled fields. The concentration of available phosphorus in eroded soils is higher with conservation tillage than with conventional tillage. Again, this is not necessarily a disadvantage since less soil erosion occurs when conservation tillage practices are employed.

The effectiveness of no-till farming is considerable. A comprehensive study performed in Georgia indicated that runoff can be reduced by 47 percent with the use of no-till farming. Soil loss can be reduced by 91 to 98 percent with the use of no-till farming compared to convention tillage (North Carolina Agricultural Extension Service, 1982). Conservation tillage can reduce pesticide and phosphorus transport by 40 to 90 percent for conservation tillage and 50 to 95 percent for no-till (EPA, 1987). Increased reliance on pesticides typically associated with conservation tillage can be avoided by implementing an integrated pest management program. Using conservation tillage without an appropriate pesticide and fertilizer management plan is not considered an acceptable BMP (EPA, 1987).

<u>All Ten Lakes</u>

For all of the ten LaGrange County lake watersheds, it is recommended that the use of conservation tillage, particularly no-till methods, be implemented. As part of the conservation tillage practices, an integrated pesticide/fertilizer management plan should also implemented to reduce the off-site migration of these chemicals.

5.2.2 Integrated Pest Management

Integrated pest management is a combination of traditional pest control methods, such as crop rotation and pesticides, with a careful monitoring of the pests to improve the efficiency of the pesticides and other controls. The amount of pesticides applied at any one time can be minimized by targeting specific pests at vulnerable points in their life cycle. The EPA/USDA Rural Clean Water program is emphasizing the need for pesticide and fertilizer management to limit groundwater contamination. Reductions in pollutant loadings range from 20 percent up to 90 percent (EPA, 1987). Since pesticides and fertilizers are applied at their most effective times and quantities, this BMP can save money in both labor and materials.

<u>All Ten Lakes</u>

As stated in Section 5.2.1, it is strongly suggested that an integrated pest management should be implemented along with any conservation tillage activities within the ten LaGrange County lake watersheds.

5.2.3 Cover Cropping

Cover cropping involves planting and growing cover and green manure crops. Cover and green manure crops are crops of close-growing grasses, legumes (clover), or small grain planted in a fallow field and plowed into the ground before the next row of crop is planted. This technique is used to control erosion during periods when the major crops do not furnish cover. In addition to erosion control, residual nitrogen from legume cover crops enhances the soil for the major commercial crops and should be considered when calculating the nitrogen requirements of these crops planted later.

The cover crop can be seeded after harvesting the major crop by light plowing or it can be seeded prior to cultivation of the major crop without additional seedbed preparation. The cover crop should be protected from grazing until it is well established and from weeds by chemical or mechanical methods as needed. Cover crops are most beneficial to farm practices that leave bare soil following harvesting.

All Ten Lakes

In the ten LaGrange County lake watersheds, planting small grain as cover or harvestable crops between corn and soybean crops would be applicable and beneficial to most of the farms in the area. Retention of moisture and nutrients plus the value of the harvested crop would probably more than offset costs of implementation.

5.2.4 Critical Area Planting

Critical area planting involves planting vegetation on critical areas to stabilize the soil and promote stormwater infiltration, thereby reducing damage from sediment erosion and excessive runoff to downstream areas. Critical areas can be sediment-producing, highly erodible, or severely eroded areas where vegetation is difficult to establish with usual seeding or planting methods.

The selection of vegetation and the use of mulching materials immediately after seeding is of special concern. Jute and excelsior matting and mulching can be used to protect soil from erosion during the period of vegetative establishment when plants are most sensitive to environmental conditions. To reinforce areas designated for planting, bank stabilization structures can be used.

Maintenance of critical area planting includes periodic inspection of seeded areas for failures. Repairs should be made as needed. If the stand is more than sixty percent damaged, the planting area should be re-established using the original planting criteria.

All Ten Lakes

It is strongly suggested that permanent vegetation should be established on all areas within the ten LaGrange County lake watersheds that are subject to severe erosion. By reducing soil erosion, both sediment and nutrient loadings to downgradient watercourses will consequently decrease, thereby resulting in improved lake water quality.

5.2.5 Terraces

A terrace is an earth embankment, ridge or channel constructed across a slope at a suitable location to intercept runoff water and control erosion. Generally terraces are considered supporting practices to use in conjunction with contouring, stripcropping and reduced tillage methods. Terracing has been shown to be highly effective in trapping sediment and reducing erosion. The effectiveness of terracing is not as good for reducing the loss of nutrients and soil from surface runoff. Subsurface nitrogen losses may increase.

A terrace can be constructed across a slope with a supporting ridge on the lower side. The use of terraces is usually not applicable below high sediment producing areas without supplementary control measures. Any sediment build-up that does occur should be removed on an as-needed basis.

The effectiveness of terraces for reducing sediment loss ranges from 50 to 98 percent and costs are approximately $2/ft.

All Ten Lakes

Within the ten LaGrange County lake watersheds, terracing will have limited applicability as an agricultural best management practice, since the regional topography is relatively flat. For those areas, where the land has very long steep slopes and is used for agricultural purposes, terracing may be useful. Under these circumstances, terracing should be considered as a viable option for controlling various forms of soil erosion.

Of the ten LaGrange County lake watersheds, the Atwood, Hackenburg and Messick Lake watersheds have the steepest slopes with only 11.1, 6.3 and 6.2 percent of the land exceeding slopes greater then 8 percent, respectively. In the Adams, Dallas, Martin, Olin, Oliver, Westler, and Witmer Lake watersheds, less than 5 percent of the land has slopes greater than 8 percent.

5.2.6 Grassed Waterways

Grassed waterways are designed to facilitate the safe disposal and transmission of surface runoff. Grassed waterways apply to both natural and constructed drainage channels. Grassed waterways may prevent 60 to 80 percent of the suspended particles in surface runoff from reaching nearby streams. Grassed waterways should be used in conjunction with other BMP's such as conservation tillage and terraces.

Constructed grassed waterways are generally shaped or graded by heavy equipment and are usually over ten feet wide at the top of the channel. Vegetation cover is usually a variety of grass or legume compatible with existing species in the area. These channels should be protected from grazing, fire and insects and should not be used as farm roads. Maintenance consists of mowing the grass and spraying if weed control is needed. If necessary, cuttings should be removed to prevent transport to nearby streams during storm events. All seeded areas should be inspected occasionally for needed repairs. Also, any sediment build-up that significantly reduces the capacity of the channel should be removed.

<u>All Ten Lakes</u>

For each of the ten LaGrange County lake watersheds, all drainage swales should be regraded and seeded with grasses that are tolerant of wet soil conditions. With proper maintenance, grassed waterways are highly effective in reducing gully erosion.

5.2.7 Grade Stabilization Structures

Soil in areas subject to heavy erosional forces, such as the outlet of a grassed waterway or a steep area which will not support vegetative cover, can be stabilized with a structure such as riprap. This is an effective method for treating small problem areas unsuitable for other stabilization methods. Construction cost for grade stabilization is approximately $500 per structure.

<u>All Ten Lakes</u>

Within all of the ten LaGrange County lake watersheds, grade stabilization structures should be established where applicable to reduce erosion.

5.2.8 Farmland Management

Farmland management incorporates several practices which discourage accelerated erosion at the farm site. The first farmland management practice is commonly referred to as pasture and hayland planting. Pasture and hayland planting involves the proper techniques that are necessary in establishing long-term stands of adapted species of perennial and biennial forage plants. The primary purpose of pasture and hayland planting is erosion control. An additional benefit could be the production of a high quality forage crop. Proper planting measures involve the adequacy and timing of lime and fertilizer application; determination of a particular area's seedbed preparation needs, seed mixtures, seeding rates, and weed control.

After pasture and hayland plantings are established, the proper maintenance of these areas is as equally important. Pasture and hayland management involves the proper treatment and use of these areas. Proper management involves the use of adapted species of grasses, time of harvest, state of plant growth and height to which plants are cut or grazed, and the control of weeds, diseases and insects. Of particular importance is establishment of grazing plans. Grazing plans should be developed to include schedules for moving animals into and out of the pasture as well as for maintenance of the pasture. Uniform, complete cover, and vigorous pasture growth are essential for control of erosion and subsequent nutrient loss. Adequate pasture facilities should be provided, including waters, shade and mineral feeders. These facilities should be periodically moved to prevent overuse in any one area. Streams, ponds, and lakes should be fenced to limit animal access.

Another farmland management practice is the control of livestock watering facilities. The development and protection of springs can be used as water supply sources of farms. Spring development involves excavation, cleaning, and capping of waterways to convey and distribute water to livestock at several locations in the farmyard and pastures. This technique distributes grazing to several points rather than concentrating it in one area. Concentrated grazing can result in overgrazing which in turn leads to accelerated erosion. Developments should be confined to springs or seepage areas that are capable of providing a dependable supply of suitable water during the planned period of use. Maintenance includes the periodic removal of sediment from spring boxes.

<u>All Ten Lakes</u>

The farmland management practices should be established within all of the ten Indiana lake watersheds. By properly establishing and maintaining pasture and hayland areas plus managing livestock watering facilities, soil erosion and nutrient enrichment of waterways due to farmland practices can be minimized.

5.2.9 Fencing

Fencing involves enclosing and dividing an area of land with a permanent structure that serves as a barrier to animals and people. The primary purpose of fencing is to control erosion by protecting sensitive areas, particularly watercourses, from the disturbance of grazing or public access, by subdividing designated grazing areas for a planned grazing system and by protecting new seedlings and plantings from grazing until they are well established. Fencing may also be a source pollution control by preventing livestock from depositing their wastes in natural watercourses.

Fencing controls streambank erosion by preventing both the physical destruction of the bank and the denuding of streambank vegetation from grazing animals. The use of filter strips between fences and the watercourses can increase the effectiveness of fencing. Fences for this purpose are not to be temporary such as electric fences. Depending on the type of animal to be restricted, the permanent fence can be woven wire, barbed wire, or high tension wire. Fences should be periodically inspected to check for broken or disconnected wire, loose staples and loose or deteriorated post or brace members.

All Ten Lakes

In each of the ten LaGrange County lake watersheds, fences should be erected around surface waters where livestock have direct access. By not allowing livestock direct access to a watercourse, both sediment and nutrient loadings to the watercourse will be drastically reduced. These loading reductions will be further enhanced by allowing buffer strips to be established between fences and nearby watercourses.

5.2.10 Agricultural Waste Storage Structures

An agricultural waste storage structure can be either an above-ground fabricated structure or an excavated pond. The above-ground fabricated structure can be either a holding tank or a manure stacking facility designed to temporarily store nontoxic agricultural and animal wastes. The primary purpose of agricultural waste storage structures is to reduce contamination of natural watercourses by source pollution control of liquid and solid wastes. Wastes can be disposed of by controlled application to cropland. Animal wastes supply soils with nutrients and soil tilth. Runoff rates are reduced and soil infiltration rates are increased with the application of animal wastes. Manure should not be applied when the ground is frozen or there is snow on the ground.

Manure stacking facilities are typically constructed of reinforced concrete, reinforced concrete block, precast panels, or treated tongue and groove lumber, and may be opened or roofed. Holding tank facilities for liquid and slurry wastes may be open or covered. Holding tanks may be located indoors, beneath slotted floors. Holding tanks can be made of cast-in-place reinforced concrete or fabricated steel with fused glass or plastic coatings.

Both holding tanks and stacking facilities should be emptied in accordance with the overall waste management plan for land application. If the holding tanks are located outdoors and are not covered, a grass waterway should be constructed downslope of the tanks to prevent surface runoff from reaching a stream or drainage channel.

A waste storage pond is an impoundment constructed by excavation or earthfill for temporary storage of nontoxic agricultural and animal wastes. When polluted runoff is stored, accumulated liquids are removed from the pond promptly after settling to ensure that sufficient capacity is available to store runoff from subsequent storms. Extraneous surface runoff should be prevented from entering the pond. The pond should be located as near to the source of waste or polluted runoff as possible. Soils under the pond should be of low to moderate permeability. Where self-sealing is not probable, the pond should be sealed by mechanical treatment or by using an impermeable membrane. Accumulated wastes should be properly disposed of as discussed above for fabricated structures. Waste storage ponds should be properly maintained including periodic inspection and clearing of inlets.

Agricultural waste storage structures can result in significant nutrient reductions because the wastes treated by these structures contains nutrients in mobile forms. In the ten lakes watershed, there are a number of livestock operations which could benefit from some type of waste storage structure. Construction costs can run from $5,000 to $15,000 depending on volume and treatment requirements.

<u>All Ten Lakes</u>

Within the ten LaGrange County lake watersheds, agricultural waste storage structures are recommended at all livestock operations. As stated in the section below, stored waste should be applied to the land under favorable soil conditions. By properly applying animal wastes to agricultural land, the majority of this waste will be retained by the underlying soils, which then allows farmers to operate in a more cost-effective manner while protecting the water quality of nearby watercourses and downstream lakes.

5.2.11 Agricultural Waste Management

Manure is a resource that should be used and managed wisely to increase crop yields and control pollution. In normal farming operation manure application provides nutrients for plant growth, improves soil tilth, and helps develop beneficial soil organisms. The use of manure as a fertilizer also decreases the erosion potential of the soil and promotes infiltration and retention of water in soil. The use of manure can reduce soil loss from sloping land by 58 to 80 percent. (North Carolina Agricultural Extension Service, 1982)

A manure management plan should be adopted for individual farms. The plan should include methods to conserve nutrients in the manure while it is being stored, to determine appropriate application rates, to determine appropriate time of application, and to determine the method of application. Methods of application typically include daily spreading, storage and periodic spreading, and subsurface injection.

<u>All Ten Lakes</u>

Within the ten LaGrange County lake watersheds, a manure management plan should be established, thereby allowing farmers to fertilize their land in a cost-effective manner and protecting the water quality of nearby watercourses.

5.2.12 Buffer Strip

Buffer strips are vegetated areas which intercept storm runoff, reduce runoff velocities, and filter out runoff contaminants. Although filter strips are similar to grassed waterways, they are primarily used along surface waters which are adjacent to urban developments, agricultural fields, and logging areas.

Successful application of buffer strips to urban developments and agricultural fields requires consideration of natural drainage patterns, steepness of slopes, soil conditions, selection of proper grass cover, filter width, sediment size distribution, and proper maintenance. All of these factors affect pollutant removals, which can range from 30 percent to over 95 percent, depending on local conditions.

Water tolerant species of vegetative cover (reed canary grass, tall fescue, Kentucky bluegrass, and white clover) should be used to maintain high infiltration rates. The type of filter strip depends upon land capability, uses of the strip, types of adjacent land use, kinds of wildlife desired, personal preferences of the landowner, and availability of planting stock or seed. Filter strips should be established at the perimeter of disturbed or impervious areas to intercept sheet flows of surface runoff. These grass buffer strips will slow runoff flow to settle particulate contaminants and encourage infiltration. Periodic inspections are necessary and thatch should be periodically removed. A recent study has shown that vegetative buffer strips with established woody undergrowth may be more effective at reducing pollutants in runoff than grass buffer strips, but presents much lower removal efficiencies in all cases (Dennis, et al., 1989).

The Classified Filter Strips Act (HEA 1604), which was passed by the Indiana General Assembly in 1991, provides tax abatement incentives for those individual who establish vegetative filter strips adjacent to ditches, creeks, rivers, wetlands or lakes. By establishing a vegetative filter strip, landowners may have those land parcels assessed at $1 per acre for property taxation purposes. Under this act, filter strips must be between 20 and 75 feet wide. For more information regarding this program, contact the county surveyor.

<u>All Ten Lakes</u>

In the ten LaGrange County lake watersheds, buffer strips would be an effective method to use in agricultural areas suffering from turn row erosion and along streams and ditches. Runoff in a field can travel along individual rows, concentrating in the areas at the ends of the rows where the plow made a sharp turn. Much of the farmed land is presently plowed right up to the ditches. Approximately 10 feet of buffer may remove around 80 percent of the total solids from runoff (EPA, 1987).

5.2.13 Impoundment Ponds, Sedimentation Basins and Wetlands

Surface water impoundments can be used to protect downstream areas from flooding, stream channel erosion, and water quality degradation from increased runoff. The basic objective is to detain stormwater and release it at a controlled rate. There are two types of impoundments. Detention basins are "dry" impoundments that temporarily store runoff and then release it to downstream surface water channels at a controlled rate. Retention basins, or ponds, are "wet" impoundments that provide "permanent" storage and release runoff waters through infiltration and evaporation. Applicability of impoundments is dependent upon the availability of sufficient land to provide the necessary impoundment volume. However, this usually is true in densely urbanized areas and may not be a concern in the agricultural areas, such as, the ten LaGrange County lake watersheds.

Impoundment ponds may be designed to maximize their effect on water quality. Upgrading of water quality is primarily achieved through sedimentation but chemical transformation and biological uptake also occurs while runoff is detained in the basin.

Impoundments can be designed for individual site control or to control runoff from multiple development sites or watershed areas. In some cases considerable economies of scale can be achieved through utilization of centralized impoundments servicing large areas. However, the need for upstream channel protection above these impoundments can reduce the anticipated savings. In areas where the anticipated nonpoint source pollutant load is expected to be particularly heavy, multiple ponds designed to perform in series may be more effective in controlling water quality. Under these circumstances, an upper pond may serve as a settling basin that releases higher quality water into a lower pond.

Impoundment ponds can trap significant quantities of sediments (65 to 90 percent) and nutrients (30 to 60 percent). However, the efficiency of the ponds depends on the runoff characteristics and the size and shape of the pond, itself. Better treatment efficiencies have been observed for fifty year record storms. Impoundment ponds should be used with other erosion control practices so that the basins do not fill up with sediment too rapidly and lose their efficiency.

Maintenance of the impoundment areas is essential. A formal maintenance plan should be formulated and should include:

1. Routine inspection and cleaning of pipe inlets and outlets for accumulated sediment and debris.

2. Critical area stabilization and vegetative control.

3. Measures to offset the production of fast-breeding insects, as necessary.

4. Periodic inspection by a qualified professional to ensure that impoundments remain structurally sound and hydraulically efficient.

This method of erosion control is potentially beneficial in several areas within the ten Indiana lake watersheds. In addition to erosion control, impoundment ponds offer enhance the aesthetic value of the immediate area. The water may draw nearby geese and other waterfowl providing recreational hunting opportunities. Under optimum conditions, the best reductions possible using sedimentation basins would be 90 percent of the total suspended solids and 60 percent of the total phosphorus, based on the results of the National Urban Runoff Program summarized by Driscoll (1983). This would require a 1 acre basin, approximately 3.5 feet deep, for every ¼ square mile of drainage area, or 3.84 acres of basin for every square mile of drainage area.

The most effective placement of basins would be to site a number of small basins with small drainage areas throughout the watershed, concentrating on areas identified as having the highest potential for pollutant runoff. Construction costs for an impoundment pond can run from $750 to $10,000, depending on the drainage area involved. Costs for constructed wetlands or sedimentation basins are considerably higher than impoundment ponds. Typically, constructed wetlands and sedimentation basins require larger areas to effectively remove incoming sediments and nutrients.

<u>All Ten Lakes</u>

Within the ten LaGrange County lake watersheds, the use of impoundment ponds should be considered in areas where other agricultural BMP's such as terracing can not be implemented. The ponds should be used in conjunction with other applicable BMP's such as grassed waterways and buffer strips. As part of proper impoundment pond maintenance, sediments must be periodically removed so that the pond functions at its design capacity.

In general, man-made wetlands and sedimentation basins are to costly to construct when designed to remove significant amounts of sediment and nutrients. Therefore, no constructed wetlands and sedimentation basins are recommended at this time until other less expensive watershed management practices are implemented. First and foremost, these other less expensive watershed BMP's are necessary to reduce the transport of sediment from lands adjacent to nearby watercourses.

5.2.14 Water Control Structures

A series of check dams can be constructed in existing drainage ditches in order to manage water level according to need. During periods of high runoff, small dams would create small detention areas and can provide some measure of flood control and check the transport of sediment, along with associated nutrients and bacteria. In winter, maintenance of water in ditches would encourage denitrification (conversion of nitrate and nitrite to N_2), reducing the nutrient load to streams and lakes, although denitrification would proceed at a slower rate during the winter months because of the lower temperatures.

All Ten Lakes

Within each of the ten LaGrange County lake watersheds, the use of check dams should be considered as a means of reducing the downstream flow of nutrients and sediments. Water control structures should be used in conjunction with grassed waterways and buffer strips. For these structures, periodic maintenance would be required to remove accumulated sediments.

5.3 Homeowner Best Management Practices

Within the ten LaGrange County lakes' watershed, homeowners may contribute a significant amount of sediments and nutrients loadings to nearby watercourses, which may eventually affect the water quality of downstream lakes. The following section discusses homeowner best management practices that are strongly recommended for all property owners in the ten lakes watershed.

5.3.1 Routine Septic Maintenance

Routine maintenance of septic systems is necessary to insure that shallow groundwater is not contaminated with chemicals and nutrients. By properly maintaining septic systems, the nutrient loadings to nearby watercourses are greatly reduced. The county health departments may aid the lake associations by performing on-site inspection of older septic systems. Failing systems should be repaired. Where clusters of failing systems are identified, the installation of small community treatment systems may be required.

5.3.2 Pesticide and Fertilizer Management

The use of pesticides and lawn fertilizers should be kept to a minimum. These chemicals should only be applied during the times when runoff is at a minimum. Within the ten LaGrange County lakes watershed, homeowners who elect to use lawn fertilizers should be encouraged to have their soils tested every 3 years. Homeowners should contact a local soil testing firm for more information regarding soil sample collection and soil analyses. Soil testing for homeowner lawns typically range from \$6 to \$10. Based on soil analyses, soil testing services generally provide both liming and fertilizing recommendations. By having their soils tested every few years, homeowners reduce the risk of over-fertilizing their lawns, which in turn reduces the amount of nutrients that may be washed into nearby lakes and streams.

5.3.3 Erosion Control

Each homeowner is encouraged to reseeded all exposed soils. By ensuring complete vegetative cover for all soils, sediment and nutrient loadings to nearby watercourses will be reduced.

5.3.4 Establishment of Buffer Strips

Homeowners with lawns that are immediately adjacent to streams and lakes should consider establishing buffer strips. Buffer strips may consist of ornamental tree and shrub plantings. By allowing a small path through the buffer strip, the homeowner still retains access to the watercourse while reducing both sediment and nutrients loadings to lakes and streams.

5.4 Watershed Management Alternatives: Wastewater Management

5.4.1 Wastewater Treatment Facilities

In many instances, septic systems may directly deliver nutrients to the shallow waters of the lake, thereby contributing to excessive macrophyte growth and algal blooms. The only way to eliminate loading from septic systems is to install a community wastewater collection and treatment system.

Of the ten lakes, the highest phosphorus loadings from septic systems were estimated for Atwood, Adams, and Oliver Lakes. Phosphorus loadings from septic systems accounted for 22, 8, and 5 percent of the total annual loading to Atwood, Adams, and Oliver Lakes, respectively.

At the present time, there are no wastewater treatment facilities in the ten LaGrange County lakes region. The Indiana Department of Environmental Management (IDEM) is currently reviewing an application for a wastewater treatment facility that would serve the residents near Adams Lake in Johnson Township, LaGrange County. The proposed facility site is a 40 acre tract of land, which is currently owned by the township and is approximately 1.5 miles south of Adams Lake along Route 550. If approved by the IDEM, the project was scheduled to go out for bid in the summer of 1991, with construction taking place as early as late 1991.

This facility, which consists of two facultative stabilization ponds in series, is designed to receive approximately 69,000 million gallon per day (MGD). Upon completion, the facility will initially serve approximately 333 dwelling units in the vicinity of Adams Lake. Effluent will be discharged into Little Elkhart Creek, which eventually feeds Mud and Nauvoo Lakes. The proposed discharge criteria from the facility into Little Elkhart Creek are as follows: a biological oxygen demand and suspended solid concentration not exceeding

30 and 70 mg/L, respectively, and a minimum dilution ratio of 10 to 1 (Jim Lauer, personal communication).

All Ten Lakes

Based on the pollutant budget for Atwood Lake, lakeside septic systems contribute a significant amount of phosphorous to the lake. Therefore, a feasibility study for a community wastewater treatment facility that would service lakeside homes and cottages should be conducted for Atwood Lake. As stated above, a wastewater treatment facility for Adams Lake is currently being reviewed by the Indiana Department of Environmental Management. Based on the pollutant budgets, Adams Lake received the second highest phosphorus loadings via lakeside septic systems. As for the remaining lakes, lake associations should work with the county health inspector to establish a septic system maintenance and inspection program. The creation of a watershed management district would help coordinate these activities.

Failing systems should be identified and repaired. If several systems are clustered together, a small community wastewater treatment system may be the solution.

5.4.2 Septic System Management

As stated under Homeowner Management Practices, septic system maintenance is very important in protecting the water quality of both groundwater and downstream watercourses. There are a number of things that homeowners can do to their septic systems is functioning properly. The following are examples of septic system Do's and Do Not's:

DO:

1. Protect the system from surface drainage. Divert downspouts and surface water away from the system.

2. Check scum and sludge levels in a septic tank at least once each year and pump if necessary.

3. Check for proper operation of aerobic tanks weekly following manufacturers instructions. It is extremely important to make sure that all components are functioning properly and that air is being continually supplied to the unit. Do not shut off aerobic tanks for vacations or other extended absences from home.

4. Protect the system and surrounding area from damage. This is especially important for elevated sand mound systems. Keep grass cut to allow sun heat to evaporate moisture.

5. Keep a record of the location and dimensions of the system. If purchasing, obtain the location and other pertinent information from the previous owner.

6. Install water saving devices.

7. Operate washing machine/dishwasher with full loads only.

DO NOT:

1. Add excessive amounts of harsh chemicals to the system. Normal household chemicals in normal amounts will not hurt the system.

2. Physically damage the system by driving over the units with heavy vehicles, digging up the system for other utility lines, etc.

3. Connect a garbage grinder to the system.

4. Pour cooking oil, fat, motor oil, etc. down the drain.

5. Put disposable diapers, sanitary napkins, tampons or other material containing non-biodegradable substances into the system.

6. Use excessive amounts of water in the home.

7. Bathe and wash clothes at the same time, or do repeated loads of washing one after the other.

8. Plant trees over or near the absorption area. Roots will enter and clog the pipes.

Attempts should be made to identify inadequate or failing systems. Septic leachate detectors may be used to identify malfunctioning septic systems along the shorelines of the ten lakes. The use of septic leachate detectors, however, is not recognized by the Environmental Protection Agency as a valid technique for identifying failing septic systems. Septic leachate surveys do not provide quantitative results. However, septic leachate surveys performed by the LaGrange County Health Department did indicate the likelihood of septic plumes entering the lakes from nearby homes. Dye studies can also be performed to determine if there are obvious malfunctions. Once a failure has been identified there are several options to correct the problem. The septic system can be replaced, modified, or the septage can be removed more frequently. If problems occur in clusters, community systems can be installed. The ultimate solution to eliminate failing septic systems is to install a wastewater collection system and a community wastewater treatment plant.

All Ten Lakes

For each of the ten LaGrange County lakes' watershed, it is recommended that the lake associations should work with the county health inspector to establish a septic system maintenance and inspection program. Failing systems should be identified and repaired. The creation of a watershed management district could help coordinate these activities.

5.5 Watershed Management Alternatives: Streambank and Roadway Stabilization

Most of the stream banks and road shoulders in the ten LaGrange County lakes' watershed are gently sloped and vegetated. However for those areas along streams and roadways exhibiting signs of severe soil erosion, streambank and roadway stabilization practices should be implemented.

5.5.1 Stream Bank Erosion Control

Although it was beyond the scope of this study to identify specific streambank erosion problems, stream bank erosion is often a significant source of the sediments and nutrients that enter a lake. Stream monitoring data along with the results of the AGNPS (Agricultural Nonpoint Source) modeling results in Appendix G should be used to identify high priority areas within the ten LaGrange County lakes region. Once identified, streambank stabilization practices can be implemented in these areas.

Stream bank erosion can be corrected in various ways: (1) by reducing the amount and velocity of water in the stream; (2) by relatively high cost structural controls such as rip-rap and gabbions; and (3) by relatively low-cost vegetative controls such as willow twigs, grasses, shrubs, or ornamental wetland plants.

Reducing the amount and velocity of water in the stream is not usually practical since existing upstream conditions dictate the present storm flow regime. However, controls can keep the existing amount and velocity of water from increasing. Creation and implementation of a Runoff Control Ordinance will minimize the increase in the amount and velocity of storm flow associated with new development, resulting in little or no increase in streambank erosion.

All Ten Lakes

All stream banks exhibiting excessive soil erosion should be identified and classified according to the degree of erosion, such as slight, moderate, or severe. After ranking all stream banks impacted by erosion, vegetative or structural controls should be implemented.

Structural stream bank erosion controls such as rip-rap or gabbions should only be implemented in severe problem areas where low-cost vegetation controls cannot be used. Low-cost vegetative controls should be used wherever practical to control moderate and severe stream bank erosion. Vegetative controls can often be planted by volunteers such as Boy Scouts and Girl Scouts. Use of volunteers enhances the benefits by adding educational and publicity aspects to the program.

The unit costs for rip-rap and gabions are estimated at $28 per cubic yard and $26 per square yard (R.S. Means Company, Inc. 1991). For these costs, rip-rap consists of random broken stone and gabions are constructed of galvanized steel mesh mats that are filled with 6 inches of stone. The above costs include equipment and labor costs to place stone. These costs do not include hauling costs for the stone, permit preparation fees, permit application fees, and equipment and labor costs for any excavation or grading work (if necessary) prior to placing stone.

Detailed design suggestions for stream bank and shoreline protection are presented in the Soil Conservation Service Technical Guide under Standards and Specifications No. 580 (1989). The county conservation districts can provide valuable technical assistance in planning shoreline stabilization projects. When streambank stabilization is proposed for legal drains in the state of Indiana, the county surveyor and the county drainage board should be contacted.

5.5.2 Roadway Erosion Control

The roads in the watershed cross many streams and drainage ways that are tributary to the ten LaGrange County lakes. Stormwater runoff from the roads and from the lands adjacent to the roads travel down the road shoulders and discharge sediments and nutrients into the waterways and eventually into the lakes.

Stream monitoring data along with the results of the AGNPS (Agricultural Nonpoint Source) modeling results in Appendix G should be used to identify high priority areas within the ten LaGrange County Lakes. Once identified, roadway erosion control practices can be implemented in these areas.

The road shoulders are maintained by the transportation department usually to cut down extraneous weeds and grass. This often results in increased stormwater runoff with increased water velocity, increased erosion, and increased pollutant loading to the waterbodies.

All Ten Lakes

All areas where stormwater from roadways are contributing excessive sediments into nearby streams and drainage ways should be identified. The degree of soil loss for the identified areas should be classified as slight, moderate, or severe. For those areas contributing large amounts of sediment to nearby watercourses or drainage ways, vegetative or structural controls should be implemented.

5.6 Water Quality Investigation

In the Oliver Lake direct watershed, a landfill facility, which is approximately 28 acres in area, was in operation during the course of this study. Based on an interview with the owner, the landfill currently accepts bulky waste items from several industries that construct boats and recreational vehicles. The landfill is located approximately one mile north of Oliver Lake and 0.1 miles from Dove Creek.

In order to assess the impacts of the county landfill on the water quality of Dove Creek, the watershed management district should investigate existing groundwater and stream water quality data near the landfill area. Data may be available through IDEM.

If insufficient water quality data is available, the watershed management district should collect water samples from Dove Creek. At a minimum, stream samples should be collected from stations located upstream and downstream of the existing fill area during baseflow and stormflow conditions.

5.7 Results of AGNPS Modeling

The Agricultural Non-Point Source (AGNPS) (Young, at al., 1990) model was used to evaluate watershed conditions during a 1 year/24 hour storm. The model was used to highlight areas that have a high potential for contributing to the pollutant load of each lake. The model is developed by dividing the direct watersheds into equally sized cells and determining over twenty input factors for each cells. Some of the factors examined where high slopes, high soil erodibility, and high sediment erosion. Model input parameters were obtained from county soil maps, cropping estimates by the County SCS office, and from 1989 aerial photographs provided by the LaGrange County ASCS office. The direct watersheds of the ten lakes were divided into 10 acre cells, with the exception of Witmer Lake, where the watershed was divided into 40 acre cells. The number of cells per direct watershed were:

Adams	344	Messick	64
Atwood	81	Olin	58
Dallas	126	Oliver	348
Hackenburg	56	Westler	118
Martin	309	Witmer	478

While AGNPS results can not pinpoint exact spots where high erosion is occurring, it provides an overall indication of those areas in the watershed where Best Management Practices should be considered. The model output identifies those areas where field personnel of the SCS and other agencies should concentrate their efforts in order to control erosion and non-point source pollution. The model was not designed to target site-specific problems or model the effects of site-specific Best Management Practices.

Land use information was obtained for the models by projecting 1989 aerial photographs of the watersheds on a USGS base map and color-coding the following land use types: forest, wetlands, row crops, pastures, and residential. Gridded overlays were used to determine the predominant land use for each cell. Crop rotation, common tillage methods, fertilization levels and conservation cropping (C) factors were obtained by personal communication with Wayne Stanger, SCS, and from a USGS map prepared by Mr. Stanger with subwatersheds marked with common factors for these parameters. Gridded overlays were used to transfer these factors to individual AGNPS cells. Existing BMP's (WASCOB, animal waste facilities, grassed waterways), areas of high gulley erosion, and the location of feedlots and livestock operations were also marked on this map and transferred to the appropriate AGNPS cells using the gridded overlays.

Soil survey maps were enlarged to 1:24,000 scale and the predominate soil types for each cell were determined using the gridded overlays. Soil characteristics, such as k factors, slope length, percent slope, LS factors, and RKLS factors were obtained from County specific soil tables provided by the SCS. Runoff curve numbers for each cell were obtained from standard runoff curve numbers tables based upon the predominant land use and soil group. A practice factor of 1.0 was used to simulate worse-case conditions, as recommended by the model's creators. Rainfall intensities came from SCS guidelines for Indiana. The balance of the model inputs were based upon model recommendations and from information in the Agricultural Handbook No. 537 (Wischmeier and Smith, 1978).

Results of the AGNPS modeling are presented in Appendix G. The results of the AGNPS modeling show that the entire ten lakes watershed contains many regions where the soils will erode easily. There are also a number of sites where erosion is between one half and one ton per acre during a 1 year, 24 hour storm. A one year, 24 hour storm would be a storm that lasts 24 hours and occurs, on average, at least once per year. Several individual lake subwatersheds had areas where erosion was greater than one ton per acre, including Atwood, Dallas, Martin, Messick, and Westler. Watershed best management practices (BMP's) should be targeted to those areas, with particular emphasis on problem areas that are close to the lakes or their tributaries.

The AGNPS model provides limited capabilities to examine the effects of best management practices on controlling watershed erosion. The AGNPS models for the ten lakes was run with a practice factor of 0.38, which simulates contour stripcropping and similar practices. Based upon these model runs, the lakes received a reduction in sediment load and suspended sediment concentration that ranged from 16 percent to 55 percent. In general, the lakes with smaller direct watersheds showed the greatest percent reduction in these factors. The percent reductions in sediment load and suspended sediment concentrations received for each lake were:

Adams	29 %	Messick	41 %
Atwood	28 %	Olin	21 %
Dallas	51 %	Oliver	55 %
Hackenburg	17 %	Westler	16 %
Martin	33 %	Witmer	41 %

We also examined the reductions in sediment erosion in each cell (cell erosion, tons/acre), sediment generated in each cell (tons), and the sediment that left each cell and passed downstream to the next cell (cell yield, tons). The average percent reduction in cell erosion ranged from 61.5 percent in the Atwood Lake direct watershed to 65.0 percent in the Martin Lake direct watershed. The average percent reduction in sediment generated within each cell ranged from 61.0 percent in the Hackenburg Lake direct watershed to 64.0 percent in the Dallas Lake direct watershed. The average percent reduction in cell yield ranged from 34.6 percent in the Hackenburg Lake direct watershed to 50.5 percent in the Witmer Lake direct watershed.

The results of this modeling indicates that aggressive watershed management could have a significant impact on the water quality of the ten LaGrange County lakes.

6.0 Recommended Management Plan for Ten LaGrange County Lakes

Based on the data collected during the diagnostic portion of this study and the research into the feasibility of various lake and watershed management techniques presented in Sections 4 and 5 of this report, a recommended program to address the water quality problems in each of the ten LaGrange County lakes has been developed. Since most of the pollutant loads originate from nonpoint sources in the drainage basin, significant improvement in lake water quality will come about slowly as land management practices are implemented throughout the watershed. In the meantime, in-lake treatment for control of aquatic plants is recommended to the extent necessary to enhance recreational use while maintaining or enhancing ecological aspects of each lake.

Population growth in the area stresses services, such as schools (LaGrange News, April 19, 1991), roads, and the environment. Now is the time to plan for growth by deciding which areas are in greatest need of protection, and how that protection is to be accomplished. Wetlands and undisturbed forested areas are important for wildlife habitat, groundwater recharge, and improvement of surface water quality. The lakes are crucial to the economic, aesthetic, and recreational well-being of the entire area.

Many of the recommended alternatives will necessitate a close working relationship among the important user groups, local residents, local government, and the advisory and regulatory agencies. Key organizations include all the lake associations, the South Central LaGrange County Water Quality Commission, the LaGrange County Health Department, the LaGrange and Noble County Soil and Water Conservation Districts, the Soil Conservation Service, the Agricultural Stabilization and Conservation Service, the LaGrange and Noble County Economic Development Departments, and the Wolcottville Town government.

6.1 Institutional

A watershed management district, which would serve the entire ten LaGrange County lakes watershed region, should be established. It is recommended that members of the South County LaGrange County Water Quality Commission (SCLCWQC) assist in the formation of this newly appointed watershed management district. The watershed management district would be responsible for overseeing all activities that may impact the water quality of all of ten lakes. The watershed management district can be formed as a non-profit organization or as a conservancy district. As a non-profit organization, the watershed management district in the ten lakes region would have no taxation or enforcement powers, hence these activities would be accomplished through the existing power base. Enforcement and taxation bodies would look to the watershed management district for guidance on watershed-related activities. In the Pocono Region of Pennsylvania, a good example of a non-profit watershed management district is the Lake Wallenpaupack Watershed Management District (LWWMD). For over ten years, LWWMD has been highly successful in protecting the water quality in Lake Wallenpaupack.

LWWMD was established in the late 1970's with the assistance of F. X. Browne Associates, Inc. As a conservancy district, the watershed management district formed around existing state laws and would therefore have the power to levy taxes.

Either as a non-profit organization or as a conservancy district, a formal organization plan for the watershed management district should be drawn up immediately so that action can begin on management activities for the ten LaGrange County lakes.

The board of directors of the watershed management district should include all appropriate government representatives, other people who can offer valuable technical and planning expertise, and at least one representative from each of the ten lake associations. The functions of the watershed management district would be as follows: 1) coordination of effort among LaGrange and Noble Counties and the Town of Wolcottville to accomplish watershed and lake management activities, 2) provision of technical and advisory assistance to local governments, homeowners, businesses, developers, and farmers, 3) development of model programs and ordinances, including erosion and sedimentation ordinances for new construction and a stormwater runoff ordinance to control water quality and flooding, for adoption by Noble and LaGrange Counties, 4) prioritization of watershed and lake management activities, which encompass the implementation of best management practices within the watershed, and further lake and watershed studies, and 5) financial management of lake and watershed programs, which includes the acquisition of state, federal and private funds to be used for various projects throughout the watershed.

Another important function of the watershed management district would be to develop educational materials and conduct educational programs for regulatory people, school children, and the public at large. One important activity which should be part of the educational program is a "Watershed Watch" program. An educational fact sheet could be distributed which describes potential pollutant sources (eroding land, gasoline, oil, or chemical spills, etc.), and gives a telephone number to contact if someone sees a possible problem.

The watershed management district would also be involved in land use planning activities which would protect or improve the water quality in the ten Indiana lakes. Such activities might include land acquisition, conservation easements, and land trusts.

6.2 Watershed Management Plan

There are some general watershed management guidelines which apply to all of the ten LaGrange County lakes watershed. Watershed management guidelines include the following: the implementation of agricultural best management practices (Ag BMP's), homeowner best management practices, wastewater management practices, and stabilization practices for both streambanks and roadways. In addition, erosion control and stormwater runoff ordinances should be established within the boundaries of the ten lakes watershed.

6.2.1 Agricultural Best Management Practices

Within the ten LaGrange County lakes watershed, the watershed management district should work closely with the LaGrange and Noble County Soil and Water Conservation Districts (SWCD), the Soil Conservation Service (SCS), and the Agricultural Stabilization and Conservation Service (ASCS) to identify all areas requiring the implementation of agricultural best management practices (Ag BMP's). In identifying these areas, the output from AGNPS modeling (included as part as this report), stream water quality data as part of this report, and field investigations should be used. Once identified, these areas should be ranked on the following criterion: benefit to water quality, cost of implementation, and participation interest of land owner. For many of the Ag BMP's, the amount of funding available will determine the number of projects completed. On the other hand, some low-cost Ag BMP's could be addressed immediately, such as restricting livestock from entering watercourses, controlling fertilizer application dosages, applying fertilizer to land during times when runoff is minimize, and creating buffer areas between agricultural fields and water bodies.

Below is a list of agricultural best management practices and their applicability in the ten LaGrange County lakes region:

> Conservation tillage (no-till) in combination with integrated pest management is strongly suggested for the ten LaGrange County lakes region. By implemented these best management practices, off-site transport of nutrients, sediment and pesticides can be minimized.
>
> Cover cropping is strongly recommended in the ten LaGrange County lakes region. By providing cover for agricultural lands throughout the year, soil losses will be minimized.
>
> Critical area planting is recommended for areas subject to high erosion. In these areas, permanent vegetation should be established, thereby reducing nutrient and sediment loadings to nearby watercourses.
>
> Terraces on lands will be of limited value in the ten LaGrange County lakes watershed since regional topography is relatively flat. In site specific areas, where long, steep slopes occur, terracing may be useful in controlling soil erosion.
>
> Grassed waterways are recommended throughout the ten LaGrange County lakes watershed. Drainage swales exhibiting excessive soil erosion should be regraded and seeded with grasses that are tolerant of wet soil conditions.

> Farmland management practices are strongly recommended in the ten LaGrange County lakes watershed. Farmland management includes both pasture and hayland management, plus the establishment buffer strips between livestock and watercourses. By implementing these farmland management practices, both nutrient and sediment loadings to the lakes will be greatly reduced.
>
> Agricultural waste storage facilities are strongly suggest in the ten LaGrange County lakes watershed. By storing animal wastes until soil conditions are conducive for land applications, nutrient loadings to nearby watercourses will be significantly reduced.
>
> Buffer strips along nearly every foot of stream/ditch is recommended. By allowing buffer strips between agricultural lands and adjacent streams and lakes, these watercourses will be protected from excessive sediment and nutrient loadings.
>
> Impoundment ponds to collect sediment and nutrients where terraces are recommended. By trapping sediments carried by runoff, downstream water courses will be protected.

Within the Oliver and Martin Lakes subwatershed areas, some agricultural best management practices (Ag BMP's) have already been implemented within the last few years by the LaGrange County Soil and Water Conservation District (LaGrange County Soil and Water Conservation District, personal communication). Some of the agricultural BMP's were federally funded by the Environmental Protection Agency under Section 319 of the Clean Water Act. In the Oliver and Martin Lakes subwatersheds, Ag BMP's were implemented or will be implemented by June 1992 at several farms. The first farm, located near the eastern end of Martin Lake, received four water and sediment control basins (WASCOB's) in cropland areas. Non-till planting practices have been implemented in the WASCOB's and all other cropland areas. Steep slopes were revegetated with warm grass species that are important food sources for wildlife. An existing seep has been conveyed to a trough, which serves as a watering station for livestock. Lastly, a fencing project, which will restrict livestock from entering a nearby tributary, will be completed by June 1992.

In the vicinity of Martin Lake, a waste utilization program has been implemented at two farms. This program includes waste storage facilities and nutrient management. The waste storage facilities allow the farmers the flexibility to spread manure under optimal soil and weather conditions. Stored manure is also tested for its available nutrient content for crop growth. The amount of manure to be applied to the land is determined by its nutrient content. Therefore, the waste utilization program limits the amount of animal wastes applied to the land and reduces the risk of nutrient export to nearby surface waters. In addition to the above farms, a pesticide management program has been established at several farms near the northeastern end of Oliver Lake (LaGrange County Soil and Water Conservation District, personal communication).

Additional agricultural BMP's have been implemented under the Agricultural Stabilization and Conservation Service's (ASCS) cost-share program, the Conservation Reserve Program under ASCS, and at the total expense of the landowner. On the south end of Olin Lake, approximately four WASCOB's have been installed under the ASCS's cost-share program. At two farms, some cropland areas have been converted to mixed stands of grasses and legumes under the Conservation Reserve Program. These farms, which are located north of Martin and Oliver Lakes, must be set aside for at least ten years. By setting aside cropland areas, farmers receive compensation by the ASCS. In one instance, a farmer restricted his livestock from entering a tributary of Oliver Lake by installing a fence. The cost for the fencing was paid in full by the landowner (LaGrange County Soil and Water Conservation District, personal communication).

6.2.2 Homeowner Best Management Practices

Within the ten lakes watershed, homeowners can make a significant contribution in reducing the amounts of sediments and nutrients loadings to nearby watercourses, which may eventually affect the water quality of downstream lakes. The watershed management district with the cooperation of the LaGrange and Noble County Soil and Water Conservation Districts (SWCD), the Soil Conservation Service (SCS), the Agricultural Stabilization and Conservation Service (ASCS), and the LaGrange and Noble County Health Departments, should educate the public with regard to homeowner best management practices through public seminars and by mail. The following homeowner best management practices, are strongly recommended.

> Routine maintenance of septic systems is critical in maintaining high water quality. By properly maintaining septic systems, the nutrient loadings to groundwater and downstream watercourses are greatly reduced. Failing septic systems may be identified by septic leachate studies and/or on-site inspections by the watershed management district with the cooperation of the county health departments. Failing systems should be repaired and where clusters of failing systems are identified, the installation of small community treatment systems may be required.

The use of pesticides and lawn fertilizers should be kept to a minimum and applied during the times when runoff is minimized. Homeowners should have their soils routinely tested. Along with test results, recommended amounts and type of fertilizers are typically offered. By applying fertilizers in the appropriate amount and under satisfactory soil conditions, nearby surface waters are further protected.

All exposed soils should be reseeded, thereby reducing sediment loadings to nearby watercourses.

In areas where lawns and watercourses are contiguous, homeowners should establish buffer strips. Buffer strips may consist of ornamental tree and shrub plantings that separate the lake or stream bank from lawns. By allowing a small path through the buffer strip, the homeowner still retains access to the watercourse and reduces both sediment and nutrients loadings to lakes and streams.

6.2.3 Wastewater Management Practices

In many instances, septic systems may directly deliver nutrients to the shallow waters of the lake, thereby contributing to excessive macrophyte growth and algal blooms. The only way to eliminate loading from septic systems is to install a community wastewater collection and treatment system.

Within the ten LaGrange County lakes watershed, the watershed management district should encourage a wastewater treatment plant feasibility study for Atwood Lake. This study should focus on septic systems in the vicinity of Atwood Lake. It has been estimated that Atwood Lake receives approximately 22 percent of its phosphorus loading from nearby septic systems.

At the present time, the Indiana Department of Environmental Management (IDEM) is currently reviewing an application for a wastewater treatment facility, which would serve the residents near Adams Lake in Johnson Township, LaGrange County. The proposed facility site is a 40 acre tract of land, which is currently owned by the township and is approximately 1.5 miles south of Adams Lake along Route 550. If approved by the IDEM, the project will go out for bid in the summer of 1991 and construction may commence as early as late 1991. Based on calculated pollution budgets, approximately 8 percent of the phosphorus loading to Adams Lake was attributable to septic systems.

On Dallas, Martin, Messick, Dallas, Hackenburg, Westler, and Witmer Lakes, septic systems should be routinely inspected by the either LaGrange and Noble County Health Departments or an outside service. In addition to inspections, failing systems may be identified by septic leachate detection studies. Failing systems should be repaired and if clusters of failing systems are identified, small community treatment system may be the solution.

6.2.4 Erosion and Runoff Control

Erosion and sedimentation ordinances and stormwater runoff ordinances should be developed for the watershed by the watershed management district, for adoption by the LaGrange and Noble County governments. There are technical manuals published by the SCS which are designed to give guidance to localities in these areas.

Erosion Control Ordinance

A model erosion and sediment control ordinance to control erosion from construction sites should be developed. The ordinance should include technical guidelines and typical details for the installation of erosion and sediment control measures. These guidelines should discuss and recommend methods for controlling soil erosion and sedimentation, including the use of silt fences, straw bales, diversions, channel lining and other erosion control measures. Details and design specifications for the installation of silt fence, straw bales, construction entrances and other standard methods should be included. Procedures for review of erosion control plans and inspections of construction sites should also be included. Some useful information regarding soil erosion control is provided in a publication entitled A Model Ordinance for Erosion Control on Sites with Land Disturbing Activities, which is put out by the Highway Extension and Research Project, and Indiana Cities and Counties (HERPICC). This publication may be obtained through the Civil Engineering Department at Purdue University in West Lafayette, Indiana.

Stormwater Runoff Control Ordinance

A model runoff control ordinance should be developed which can be adopted and implemented by LaGrange and Noble Counties. Unlike the proposed erosion and sediment control ordinance which is designed to control erosion and runoff during construction activity, the runoff control ordinance is designed to control erosion and runoff after construction activities are complete, for the life of the project.

The runoff control ordinance should be developed on the basis of the environmental performance standards that the peak stormwater runoff and the pollutant loads from a new development or facility shall not exceed the pre-development levels.

The runoff control ordinance should include methods for calculating runoff flows and velocities, design storm requirements, rate of runoff control requirements and water quality standards. If detention or retention facilities are required, the ordinance should include design standards for these facilities for freeboard, emergency spillways, bottom slope and other technical or safety requirements. The ordinance should also include procedures for an engineering review of the plan and inspections during construction.

Streambank Stabilization

The watershed management district should identify areas of streambank erosion and classify the erosion of those areas as slight, moderate, or severe. Streambank erosion can be corrected by 1) reducing the amount and velocity of water in the stream, 2) installing relatively high cost structural controls such as rip-rap and gabions, and 3) installing relatively low-cost vegetative controls such as willow twigs, shrubs or grasses. Low-cost vegetative controls should be used wherever practical to control moderate and severe streambank erosion. Trees, grasses, and shrubs which can withstand both desiccation and submersion are recommended. The LaGrange and Noble County Soil and Water Conservation Districts' can provide technical assistance. Vegetative controls can often be planted by volunteers such as Boy Scouts and Girl Scouts. Use of volunteers enhances the benefits by adding educational and publicity aspects to the program. When streambank stabilization is proposed in legal drains, both the county surveyors and the county drainage board should be consulted.

Roadway Erosion Control

The watershed management district should identify roadway and stream crossing problem areas and classify the problem areas as slight, moderate, or severe. Both structural and vegetative controls should be used to reduce the sediment and nutrient entering the waterways.

6.2.5 Water Quality Investigation

In order to assess the impacts of the county landfill on the water quality of Dove Creek, the watershed management district should investigate existing groundwater and stream water quality data near the landfill area. Data may be available through IDEM. Dove Creek is located in the Oliver Lake watershed and is a tributary to Oliver Lake. Oliver Lake is a water source for both Hackenburg and Messick Lakes.

If insufficient water quality data is available, the watershed management district should collect water samples from Dove Creek. At a minimum, stream samples should be collected from stations located upstream and downstream of the existing fill area during baseflow and stormflow conditions. Some suggested test parameters are total petroleum hydrocarbons, total organic halogens, volatile organic compounds, heavy metals, pH, and conductivity.

6.3 In-Lake Management Plan

For the ten LaGrange County lakes, the success of in-lake management strategies is highly dependent on the success of watershed best management practices. Watershed best management practices (Ag BMP's, homeowner best management practices, wastewater management practices, and stormwater and roadway erosion control practices) can significantly reduce the amount of incoming nutrients and sediments to a lake from the surrounding watershed. By reducing the quantity of incoming nutrients and sediments to a lake, the water quality of a lake is expected to gradually improve. Therefore, watershed management practices should be implemented prior to any recommended in-lake management strategies. If lake water quality has not improved through the implementation of watershed best management practices, recommended in-lake management practices other than aquatic macrophyte control should be reevaluated. Nuisance aquatic macrophytes can be controlled at the present time.

In contrast to the watershed management plans, in-lake management plans are tailored to individual lakes. In-lake management plans must take into account the physical, chemical and biological characteristics of the lake in question and its surrounding watershed; therefore, what is recommended for one lake may be inappropriate for another lake. In addition to the applicability of the in-lake restoration alternative, an in-lake restoration alternative must also be cost-effective, impose few if any negative impacts to the environment, and should benefit a substantial number of lake users. Based on the above criterion, recommended in-lake management alternatives for each of the ten LaGrange County lakes are discussed below.

6.3.1 Adams Lake

For Adams Lake, the in-lake management plan is primarily geared towards controlling aquatic macrophytes in an environmentally sound manner, improving public access, and reducing internal phosphorus loadings from sediments. In contrast to the use of herbicides, an integrated approach should be used in controlling high densities of aquatic plants that impair navigation. In the vicinity of docks, dense aquatic plant growth can be controlled by installing benthic barriers, thereby enhancing the navigation between lakeside properties and open waters. For the best results, benthic barriers should be installed in early spring and removed at the of the season. In weed choked channels, weed harvesting equipment is recommended. Aquatic plant harvesting can improve channel access to open waters and where lakeside property owners desire access to the main channel, benthic barriers may be installed. It is recommended that stands of aquatic plants that do not severely impair navigation or other lake uses be left in their natural setting. In many instances, stands of macrophytes are very important to the lakes's biota by providing nurseries for juvenile fish, cover and spawning areas for adult fish, and food and cover for wildlife.

After watershed management practices (includes wastewater treatment facility for lakeside residents) are implemented, nutrient inactivation should be reevaluated if lake water quality does not improve. The reevaluation of nutrient inactivation should occur after the lake has had sufficient time to respond to the recommended watershed management practices. Nutrient inactivation, using alum salts, may be cost-effective approach in reducing internal phosphorous loadings via lake sediments.

6.3.2 Atwood Lake

For Atwood Lake, the in-lake management plan is primarily focused towards controlling aquatic macrophytes in an environmentally sound manner and reducing internal phosphorus loadings from sediments. As opposed to the use of herbicides, an integrated approach should be used in controlling high densities of aquatic plants that impair navigation. In the vicinity of docks, dense aquatic plant growth can be controlled by installing benthic barriers, thereby enhancing the navigation between lakeside properties and open waters. For the best results, benthic barriers should be installed in early spring and removed at the of the season. Aquatic plant harvesting is recommended at the following areas: the shallow area along the western shoreline and the point along the southern shoreline near the campground. Aquatic plant harvesting is also recommended for the channel, which provides public access to the lake via the public boat launch. It is recommended that stands of aquatic plants that do not severely impair navigation or other lake uses be left in their natural setting.

In addition to controlling aquatic plants, a feasibility study for a wastewater treatment facility should be conducted. Based on calculated pollutant budgets for all ten lakes, Atwood Lake recorded the highest phosphorus loading due to lakeside septic systems. Once phosphorous loadings from septic systems and other land uses within the watershed are reduced, hypolimnetic aeration and nutrient inactivation alternatives should be reevaluated if lake water quality does not improve. The reevaluation of hypolimnetic aeration should occur after the lake has had sufficient time to respond to the recommended watershed management practices.

6.3.3 Dallas Lake

For Dallas Lake, the in-lake management plan is geared towards controlling aquatic plants in an environmentally sound manner. As opposed to the use of herbicides, an integrated approach should be used in controlling high densities of aquatic plants that impair navigation. In the vicinity of docks, dense aquatic plant growth can be controlled by installing benthic barriers, thereby enhancing the navigation between lakeside properties and open waters. For the best results, benthic barriers should be installed in early spring and removed at the of the season. In weed choked channels, weed harvesting equipment is recommended. Aquatic plant harvesting can improve channel access to open waters and where lakeside property owners desire access to the main channel, benthic barriers may be installed. It is recommended that stands of aquatic plants that do not severely impair navigation or other lake uses be left in their natural setting.

6.3.4 Hackenburg Lake

For Hackenburg Lake, the in-lake management plan is geared towards controlling aquatic plants in an environmentally sound manner. As opposed to the use of herbicides, an integrated approach should be used in controlling high densities of aquatic plants that impair navigation. In the vicinity of docks, dense aquatic plant growth can be controlled by installing benthic barriers, thereby enhancing the navigation between lakeside properties and open waters. For the best results, benthic barriers should be installed in early spring and removed at the of the season. Aquatic plant harvesting is recommended near the shallow areas in the vicinity of the lake's outlet. In weed choked channels, weed harvesting equipment is recommended. Aquatic plant harvesting can improve channel access to open waters and where lakeside property owners desire access to the main channel, benthic barriers may be installed.

It is recommended that aquatic vegetation along the northern shoreline remain in its existing condition. In most instances, aquatic vegetation along a lake's shoreline is very important to the aquatic biota by providing nurseries for juvenile fish, cover and spawning areas for adult fish, and food and cover for wildlife.

6.3.5 Martin Lake

For Martin Lake, the in-lake management plan is directed towards controlling aquatic vegetation in an environmentally sound manner. As opposed to the use of herbicides, benthic barriers should be installed around docks where navigation to open waters is impaired by dense plant growth. For the best results, benthic barriers should be installed in early spring and removed at the of the season. As for the remainder of the lake, it is recommended that stands of aquatic plants that do not severely impair navigation or other lake uses be left in their natural condition. This is especially true for the vegetation located along the eastern shoreline of the lake. These stands of aquatic plants are likely responsible for reducing both nutrient and sediment loadings to the lake from two inflowing tributaries.

6.3.6 Messick Lake

For Messick Lake, the in-lake management plan focuses on controlling aquatic vegetation in an environmentally sound manner, increasing the water depth near and in the northern inlet, and reducing internal phosphorus loadings from sediments. In contrast to the use of herbicides, an integrated approach should be used in controlling high densities of aquatic plants that impair navigation. In the vicinity of docks, dense plant growth can be controlled by installing benthic barriers, thereby enhancing the navigation between lakeside properties and open waters. For the best results, benthic barriers should be installed in early spring and removed at the of the season. In weed choked channels, weed harvesting equipment is recommended. Aquatic plant harvesting can improve channel access to open waters and where lakeside property owners desire access to the main channel, benthic barriers may be installed. It is recommended that stands of aquatic plants that do not severely impair navigation or other lake uses be left in their natural condition.

In addition to installing benthic barriers, in-lake sediment dredging is recommended for the eastern shoreline near the northern inlet, the northern inlet, and two lateral channels which extend into the northern inlet. After dredging, the minimum water depth for these areas should be approximately five feet, to enhance navigation. Another benefit associated with in-lake dredging is that dense stands of aquatic vegetation are controlled by physically removing nutrient rich sediments, existing plants, and their associated root structures.

After watershed management practices are implemented, hypolimnetic aeration should be reevaluated if lake water quality does not improve. The reevaluation of hypolimnetic aeration should occur after the lake has had sufficient time to respond to the recommended watershed management practices. Hypolimnetic aeration may be a cost-effective restoration alternative for controlling internal phosphorous loadings from lake sediments and restoring oxygen to the bottom waters during summer stratification.

6.3.7 Olin Lake

No in-lake management plan is offered for Olin Lake since its water quality is good and this undeveloped lake is currently classified as a natural preserve area by the state of Indiana.

6.3.8 Oliver Lake

For Oliver Lake, the in-lake management plan focuses on controlling aquatic vegetation in an environmentally sound manner, and increasing the water depth at the mouth of Dove Creek and at the public boat launch channel. In contrast to the use of herbicides, dense aquatic plant growth in the vicinity of docks can be controlled by installing benthic barriers, thereby enhancing the navigation between lakeside properties and open waters. For the best results, benthic barriers should be installed in early spring and removed at the of the season. It is recommended that stands of aquatic plants that do not severely impair navigation or other lake uses be left in their natural condition.

In addition to installing benthic barriers, in-lake sediment dredging is recommended for the inlet of Dove Creek and the adjacent channel, which contains the public boat launch. After dredging, the minimum water depth for these areas should be approximately five feet; thereby enhancing public access to open waters. Another benefit associated with in-lake dredging is that dense stands of aquatic vegetation are controlled by physically removing nutrient rich sediments, existing plants, and their associated root structures.

6.3.9 Westler Lake

For Westler Lake, the in-lake management plan focuses on controlling aquatic vegetation in an environmentally sound manner, and reducing internal phosphorus loadings from sediments. In contrast to the use of herbicides, an integrated approach should be used in controlling high densities of aquatic plants that impair navigation. In the vicinity of docks, dense plant growth can be controlled by installing benthic barriers, thereby enhancing the navigation between lakeside properties and open waters. For the best results, benthic barriers should be installed in early spring and removed at the of the season. In weed choked channels, weed harvesting equipment is recommended. Aquatic plant harvesting can improve channel access to open waters and where lakeside property owners desire access to the main channel, benthic barriers may be installed. It is recommended that stands of aquatic plants that do not severely impair navigation or other lake uses be left in their natural condition.

After watershed management practices are implemented, hypolimnetic aeration should be reevaluated if lake water quality does not improve. The reevaluation of hypolimnetic aeration should occur after the lake has had sufficient time to respond to the recommended watershed management practices. Hypolimnetic aeration may be a cost-effective restoration alternative for controlling internal phosphorous loadings from lake sediments and restoring oxygen to the bottom waters during summer stratification.

6.3.10 Witmer Lake

For Witmer Lake, the in-lake management plan is primarily geared towards controlling aquatic vegetation in an environmentally sound manner, increasing the water depth in lateral channel which interconnects four northern channels, and reducing internal phosphorus loadings from sediments. In contrast to the use of herbicides, an integrated approach should be used in controlling high densities of aquatic plants that impair navigation. In the vicinity of docks, dense plant growth can be controlled by installing benthic barriers, thereby enhancing the navigation between lakeside properties and open waters. For the best results, benthic barriers should be installed in early spring and removed at the of the season. In weed choked channels, weed harvesting equipment is recommended. Aquatic plant harvesting can improve channel access to open waters and where lakeside property owners desire access to the main channel, benthic barriers may be installed. It is recommended that stands of aquatic plants that do not severely impair navigation or other lake uses be left in their natural setting.

In addition to controlling macrophytes, in-lake sediment dredging is recommended for the shallow lateral channels which interconnect four northern channels. By increasing the water depth in these laterals, navigation between these channels will be enhanced.

After watershed management practices are implemented, nutrient inactivation should be reevaluated if lake water quality does not improve. The reevaluation of nutrient inactivation should occur after the lake has had sufficient time to respond to the recommended watershed management practices. Nutrient inactivation, using alum salts, may be cost-effective approach in reducing internal phosphorous loadings via lake sediments.

7.0 Environmental Evaluation

Since socio-economic and environmental impacts are part of the cost-effectiveness analysis for the restoration of the ten Indiana lakes, many of these impacts were addressed during the evaluation of restoration alternatives. However, the impacts and their mitigative measures are formally documented below using the environmental evaluation checklist in the Clean Lakes Program Guidance Manual (U.S. EPA, 1980).

1. Will the project displace people?

   No.

2. Will the project deface existing residences or residential areas?

   No. Residential areas are not affected by the proposed plan.

3. Will the project be likely to lead to changes in established land use pattern or an increase in development pressure?

   Possibly. If a sewer system is expanded or installed, developmental pressures could increase. Improving agricultural lands through the installation of BMP's may actually enhance the desirability of the land for continued agricultural usage.

4. Will the project adversely affect prime agricultural land or activities?

   No. The recommended Best Management Practices (BMP's) will reduce sediment and nutrient losses from cropland and pastureland and should benefit agricultural activities.

5. Will the project adversely affect parkland, public land or scenic land?

   No. Restoration activities will greatly enhance the recreational and aesthetic uses of the lake and adjacent park, public and scenic land.

6. Will the project adversely affect lands or structures of historic, architectural, archeological or cultural value?

   The project as planned involves no modifications to or activities which will impact existing structures. No lands which have not already been altered by agricultural or other development activities will be affected.

7. Will the project lead to a significant long-range increase in energy demands?

   The selected restoration alternatives will not cause any significant increases in energy demand over the long-term.

8. Will the project adversely affect short-term or long-term ambient air quality?

   Air quality may be affected over the short-term due to construction activities associated with agricultural BMP installation. All construction equipment should have proper emission controls and proper dust control practices should be used. Modern aquatic weed harvesters should not adversely affect air quality if properly maintained and operated.

9. Will the project adversely affect short-term or long-term noise levels?

   Noise levels may be temporarily affected by harvesting and construction activities. All construction vehicles and equipment should use noise control devices.

10. If the project involves the use of in-lake chemical treatment, will it cause any short-term or long-term effects?

    No in-lake chemical treatments are recommended.

11. Will the project be located in a floodplain?

    Some of the proposed agricultural BMP's and stream bank stabilization activities would be located in floodplains, although no adverse effects are expected.

12. Will structures be constructed in the floodplain?

    The use of check dams and detention/retention basins are recommended. Check dams are to be installed within a stream's corridor, therefore check dams will evidently fall within the boundaries of a floodplain. Retention/detention basins may or may not be sited within the boundaries of a floodplain. The actual location of a proposed basin will be highly dependent on local site conditions. The outfall structure of a basin will discharge runoff directly into an adjacent watercourse; hence these structures will also need to be constructed within a floodplain.

Prior to any construction activities associated with the above structures, all the necessary state and/or federal permits will be submitted. The construction of a check dam or a detention/retention basin will only commence after receiving final approval in writing by the appropriate state and federal agencies.

13. If the project involves physically modifying the lake shore, its bed, or its watershed, will the project cause any short or long-term adverse effects?

    In-lake dredging activities might cause temporary increases in lake turbidity. Other construction activities could result in the transportation of nutrients, sediments or other pollutants to downstream waters. All earthmoving activities will be conducted in a way to minimize the erosion potential and minimize in-lake turbidity.

14. Will the project have a significant adverse effect on fish and wildlife, wetlands or other wildlife habitat?

    No adverse effects are expected. The planting of buffer strips, streambank stabilization, and revegetation of exposed eroding areas will have secondary benefits and will expand habitat areas for birds and mammals. As for in-lake dredging and the installation of benthic barriers, the loss of habitat for fish and benthic organisms is inevitable, but the proposed areas that will be affected are only a minute fraction of total available habitat in each of the ten lakes.

15. Have all feasible alternative to the project been considered in terms of environmental impacts, resource commitment, public interest and cost?

    All feasible alternatives for restoring the ten Indiana lakes have been thoroughly analyzed. The recommended plan has minimal negative environmental impacts, and implementation of BMP's will improve management of land resources and water quality. Because of the complexity of the problems encountered in these lakes and their watershed, the recommended approach using both in-lake and watershed management practices appears to be the most cost-effective method to improve fishing, boating, aesthetics, and other lakeside uses.

16. Are there other measures not previously discussed which are necessary to mitigate adverse impacts resulting from the project?

    There are no possible mitigation measures known at the present time which have not been discussed.

8.0 Public Participation

A public meeting was held in August 1991. At that time, the results of the lake monitoring program were presented along with the analysis of restorative and management alternatives. The objective of this meeting was to inform the public on the water quality status of the ten Indiana lakes, present the conclusions and recommendations of this report, answer any questions regarding the ten lakes study, and receive the public's input regarding proposed lake and watershed restoration alternatives.

The public meeting was well attended and received favorably by those in attendance. No direct comments or questions were received besides questions about particular aspects of the study, primarily regarding water quality.

9.0 Implementation Program

In order to implement the recommended management plan for the ten LaGrange County lakes, a plan of action is needed, setting forth a schedule of target dates for specific activities, and potential funding sources. The following sections describe potential federal and state funding programs, water quality monitoring and documentation necessary for assessment of the effect of restoration methods on water quality, and a summary and schedule of the management plan for each of the ten LaGrange County lakes.

9.1 Financial Assistance

Recent trends in state and federal funding indicate that implementation of the recommended management plans for the ten LaGrange County lakes may have to derive funds from a variety of sources. The following is a description of additional state and federal funding that may be available for these ten Indiana lakes.

Once a lake feasibility study has been conducted under The Indiana Department of Natural Resources' Lake Enhancement Program, additional state funding for the implementation of both lake and watershed management plans may be available through the Department. The actual implementation of lake and watershed management plans may be funded through the Department's Lake Enhancement Program and the Lake and Watershed Land Treatment Program, respectively.

Under the Federal Water Pollution Control Act (Clean Water Act) as amended by Water Quality Act of 1987 (P.L. 100-4), the U.S. Environmental Protection Agency (EPA) administers funding for lake diagnostic-feasibility studies and the implementation of lake restoration and watershed best management practices. Under Section 314, the Clean Lakes Program, federal funding is available for Phase I lake studies and Phase II projects. Phase I studies are focused on diagnosing lake problems and developing feasible lake restoration alternatives. Phase II projects are aimed at lake restoration by implementing those recommendation offered as part of the Phase I studies. Under Section 319, Nonpoint Source Management Programs, federal funding is available for the implementation of agricultural best management practices to reduce agricultural nonpoint sources of pollution.

The ten LaGrange County lakes study, which was funded under Indiana's Lake Enhancement Program, does not meet the requirements of an EPA Phase I study. Therefore, the ten LaGrange County lakes do not qualify for EPA funding for Phase II projects under Section 314, but these lakes may qualify for Phase I funding under Section 314 and additional funding under Section 319.

In addition to the state's Lake and Watershed Land Treatment Program, and the EPA's Nonpoint Source Management Programs, several other programs are available to help defray the costs of implementing agricultural best management practices. The Agricultural Conservation Program under the U.S. Department of Agriculture, Soil Conservation Service, is a cost-sharing program, which funds 75 percent of costs for a particular agricultural best management practice up to $3,500 per year per farm. Similarly to the Soil Conservation Service, several other cost-sharing programs are available to individual land owners through the Agricultural Stabilization and Conservation Service (ASCS).

9.2 Future Monitoring

With or without state or federal funding, a baseline monitoring program for the ten LaGrange County lakes should continue, thereby documenting the water quality status of all ten lakes. For any lake system, the early detection of water quality deterioration is extremely important and the documentation of the lake's physical, biological and chemical status may prove to be an invaluable source of information with regard to future work at any of the ten lakes or within the boundaries of the ten lakes watershed.

The watershed management district should encourage individuals within the watershed to get involved with the Volunteer Lake Monitoring Program offered by the Indiana Department of Environmental Management (IDEM).

9.3 Management Plan Schedule and Summary

The management plan for the ten LaGrange County lakes is subdivided into a watershed management plan and individual lake management plans. In the paragraphs to follow, a watershed management plan and lake management plans for each of the ten LaGrange County lakes are presented below.

9.3.1 Watershed Management Plan

Due to the fact that all ten LaGrange County lakes are hydrologically interconnected, the water quality of downstream lakes are indirectly influenced by all upstream watershed activities. Therefore, it is of the utmost importance that a watershed management plan, serving the entire ten LaGrange County lakes watershed, be established. The ten LaGrange County lakes watershed management plan primary goal is to reduce nutrient and sediment losses from lands located throughout the entire watershed. The watershed management district should also investigate existing groundwater and stream water quality data in the vicinity of the County landfill. The county landfill is located in the Oliver Lake direct watershed area. If insufficient water quality data is available, the watershed management district should collect water samples from Dove Creek as stated in Section 6.2.5. The watershed management plan for the entire ten LaGrange County lakes region is summarized in Table 8.1.

Table 8.1
Ten LaGrange County Lakes Watershed Management Plan

Activity	Target Date
Formation of the Ten LaGrange County Lakes Watershed Management District	Spring 1992.
Identify and apply for funding	Immediately after Watershed Management District is formed, ongoing.
Develop erosion control ordinance	Spring/Summer 1992.
Develop stormwater runoff ordinance	Spring/Summer 1992.
Public education	Summer 1992. Ongoing.
Identify areas requiring the implementation of agricultural best management practices	Summer 1992. Ongoing
Investigate groundwater and surface water quality in the vicinity of the County landfill.	Fall 1992.
Implement groundwater investigation at	1992
Inspect septic system and investigate alternatives	1992
Identify areas in need of streambank stabilization, implement stabilization	1992. Ongoing.
Identify areas in need of roadway stabilization, implement stabilization	1992. Ongoing.

9.3.2 Lake Management Plans

For each of the ten LaGrange County lakes, lake management plans are summarized in Tables 8.2 through 8.11. All lake management plans should be coordinated through the newly appointed watershed management district. The district would also be responsible for seeking out funds for both watershed and lake management plans. For the majority of the ten lakes, lake management plans are primarily focused on controlling aquatic vegetation that are currently treated by herbicides, and on providing better access for the public at large. Other in-lake restoration alternatives, such as nutrient inactivation and hypolimnetic aeration, should be reevaluated at a later date when both nutrient and sediment loadings are significantly reduced.

After watershed best management practices (BMP's) are implemented, hypolimnetic aeration and nutrient inactivation should be reevaluated if lake water quality does not improve. The reevaluation of hypolimnetic aeration and nutrient inactivation should occur after the lake has had sufficient time to respond to the recommended watershed management practices. Hypolimnetic aeration and nutrient inactivation may be a cost-effective restoration alternative for controlling internal phosphorous loadings from lake sediments and restoring oxygen to the bottom waters during summer stratification.

<u>Adams Lake</u>

As shown in Table 8.2, the management plan for Adams Lake includes the installation of benthic barriers in the vicinity of docks, weed harvesting in channels, and in-lake sediment dredging near the public boat launch. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting, and does not include installation fees or special materials, such as benthic anchors. Weed harvesting in channels is approximately $375 per acre and does not include hauling fees to the disposal site. Sediment dredging to increase the water depth near the public boat launch is estimated at $30,659 for the removal of 1,333 cubic yards of sediment.

For Adams Lake, nutrient inactivation may be cost-effective after watershed BMP's have been implemented, which includes the construction of the proposed community wastewater treatment facility. After watershed BMP's have been implemented, nutrient inactivation should be reevaluated if lake water quality does not improve. Reevaluation of nutrient inactivation should occur after the lake has had sufficient times to respond to watershed BMP's.

Table 8.2 Lake Management Plan for Adams Lake	
Activity	**Target Date**
Installation of Benthic Barriers	Spring 1992.
Weed Harvesting (Channels)	Spring 1992.
Sediment Dredging (near public boat launch)	Summer/Fall 1992.
Nutrient Inactivation	Reevaluate after nutrient and sediments loadings have been reduced

Atwood Lake

As shown in Table 8.3, the management plan for Atwood Lake includes the installation of benthic barriers in the vicinity of docks, weed harvesting in both the lake and channels, and conducting a feasibility study for the constructing a community wastewater treatment facility. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting, and does not include installation fees or special materials, such as benthic anchors. Weed harvesting is approximately $225 and $375 per acre in open waters and channels, respectively. The above weed harvesting costs do not include hauling fees to the disposal site.

In addition to managing nuisance weeds, a feasibility study for a community wastewater treatment system should be conducted. The proposed treatment system should service lakeside property owners that are currently discharge wastewater to on-site septic systems. As part of this study, innovative technologies for effluent discharges, such as spray irrigation, should be fully investigated. The feasibility study can possibly be performed by the LaGrange County sewer district. The other option is to contract-out the study to a private environmental engineering firm with expertise in wastewater treatment design. For a study of this magnitude, the estimated cost may range from $10,000 to $25,000.

For Atwood Lake, hypolimnetic aeration may be cost-effective after the both nutrient and sediment loadings from nonpoint sources are reduced. After nutrient and sediment loadings have been significantly reduced and lake water quality does not improve, hypolimnetic aeration should be reevaluated at this time.

Table 8.3
Lake Management Plan for Atwood Lake

Activity	Target Date
Installation of Benthic Barriers	Spring 1992.
Weed Harvesting (Lake and Channels)	Spring 1992.
Feasibility Study for Wastewater Treatment Facility	Summer 1992.
Hypolimnetic Aeration	Reevaluate after nutrient and sediment loadings are reduced.
Nutrient Inactivation	Revaluate after nutrient and sediment loadings are reduced.

Dallas Lake

As shown in Table 8.4, the management plan for Dallas Lake includes the installation of benthic barriers in the vicinity of docks, and weed harvesting in channels. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting and does not include installation fees or special materials, such as benthic anchors. Weed harvesting in channels is approximately $375 per acre and does not include hauling fees to the disposal site.

Table 8.4
Lake Management Plan for Dallas Lake

Activity	Target Date
Installation of Benthic Barriers	Spring 1992.
Weed Harvesting (Channels)	Spring 1992.

Hackenburg Lake

As shown in Table 8.5, the management plan for Hackenburg Lake includes the installation of benthic barriers in the vicinity of docks, and weed harvesting in channels and near the lake's outlet. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting and does not include installation fees or special materials, such as benthic anchors. Weed harvesting in open waters and channels is approximately $225 and $375 per acre, respectively. The above weed harvesting fees do not include hauling fees to the disposal site.

Table 8.5
Lake Management Plan for Hackenburg Lake

Activity	Target Date
Installation of Benthic Barriers	Spring 1992.
Weed Harvesting (Near Outlet, Channels)	Spring 1992.

Martin Lake

As shown in Table 8.6, the management plan for Martin Lake consists only of controlling nuisance weeds by installing benthic barriers in the vicinity of docks. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting and does not include installation fees or special materials, such as benthic anchors.

Table 8.6
Lake Management Plan for Martin Lake

Activity	Target Date
Installation of Benthic Barriers	Spring 1992.

Messick Lake

As shown in Table 8.7, the management plan for Messick Lake includes the installation of benthic barriers in the vicinity of docks, weed harvesting in channels, and in-lake sediment dredging near the public boat launch. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting, and does not include installation fees or special materials, such as benthic anchors. Weed harvesting in channels is approximately $375 per acre and does not include hauling fees to the disposal site. Sediment dredging to increase the water depth in the northern channel is estimated $230,069 for the removal of 10,003 cubic yards of sediment.

For Messick Lake, hypolimnetic aeration may be cost-effective after the both nutrient and sediment loadings from nonpoint sources are reduced. After nutrient and sediment loadings have been significantly reduced and lake water quality does not improve, hypolimnetic aeration should be reevaluated at this time.

Table 8.7
Lake Management Plan for Messick Lake

Activity	Target Date
Installation of Benthic Barriers	Spring 1992.
Weed Harvesting (Channels)	Spring 1992.
Sediment Dredging (Northern Inlet)	Summer/Fall 1992.
Hypolimnetic Aeration	Reevaluate after nutrient and sediment loadings are reduced.

Olin Lake

As shown in Table 8.8, no lake restoration activities are recommended in the management plan for Olin Lake. This is primarily due to the fact that Olin Lake is classified as a natural preserve area by the State of Indiana.

Table 8.8 Lake Management Plan for Olin Lake	
Activity	
None	Since Olin Lake consists of undeveloped shorelines and is classified a natural preserve by the State of Indiana, no in-lake management plan is offered

Oliver Lake

As shown in Table 8.9, the management plan for Oliver Lake includes the installation of benthic barriers in the vicinity of docks, and weed harvesting in channels. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting and does not include installation fees or special materials, such as benthic anchors. Weed harvesting in channels is approximately $375 per acre and this cost does not include hauling fees to the disposal site.

Table 8.9 Lake Management Plan for Oliver Lake	
Activity	**Target Date**
Installation of Benthic Barriers	Spring 1992.
Weed Harvesting (Channels)	Spring 1992.

Westler Lake

As shown in Table 8.10, the management plan for Westler Lake includes the installation of benthic barriers in the vicinity of docks, and weed harvesting in channels. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting and does not include installation fees or special materials, such as benthic anchors. Weed harvesting in channels is approximately $375 per acre and this cost does not include hauling fees to the disposal site.

Table 8.10
Lake Management Plan for Westler Lake

Activity	Target Date
Installation of Benthic Barriers	Spring 1992.
Weed Harvesting (Channels)	Spring 1992.

Witmer Lake

As shown in Table 8.11, the management plan for Witmer Lake includes the installation of benthic barriers in the vicinity of docks, and weed harvesting in channels. For benthic barriers, the estimated cost to cover an area of 400 square feet is $40 for polypropylene materials and $120 for fiberglass netting and does not include installation fees or special materials, such as benthic anchors. Weed harvesting in channels is approximately $375 per acre and this cost does not include hauling fees to the disposal site.

Table 8.11
Lake Management Plan for Witmer Lake

Activity	Target Date
Installation of Benthic Barriers	Spring 1992.
Weed Harvesting (Channels)	Spring 1992.

9.4 Permit Requirements

Based on conversations with representatives of the Indiana Department of Natural Resources (IDNR) the Indiana Department of Environmental Management (IDEM) and the United States Department of the Army, Corps of Engineers the following is a list of permit requirements for the recommended watershed and in-lake restoration methods.

9.4.1 In-lake Methods

Weed Harvesting	no permit requirements as long as root structures are not disturbed.
Herbicides	Weed Control Permit must be submitted to IDNR ($5). Available for control of submersed macrophytes plus duckweed and purple loosestrife.
Benthic Barriers	Proposal must be submitted to IDNR. 404 Permit may be required by the Corps of Engineers ($10 - $100).
Nutrient Inactivation	Proposal to IDNR and IDEM. 404 Permit may be required by the Corps of Engineers ($10 - $100).
Sediment Dredging	Lake Preservation Act Permit may be required. Construction in a Floodway Permit may be required. Ditch Act Permit may be required. 404 Permit must be submitted to Corps of Engineers ($10 - $100).
Hypolimnetic Aeration	Proposal must be submitted to IDNR.

9.4.2 Watershed Methods

Check Dams	Construction in a Floodway Permit must be submitted to IDNR ($50). 404 Permit maybe required by the Corps of Engineers ($10 - $100).
Retention\ Detention Basins	Construction in a Floodway Permit must be submitted to IDNR ($50). 404 Permit maybe required by the Corps of Engineers ($10 - $100).

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See Volume 2 for the Appendices:

Appendix A Bathymetric and Sediment Profile Maps
Appendix B Primer on Lake Ecology
Appendix C Glossary of Lake and Watershed Management Terms
Appendix D Water quality data
Appendix E Macrophyte Maps
Appendix F Sediment Data
Appendix G Results of AGNPS modeling